OPINION REGARDING POSSIBLE PRESSURE COMMUNICATION BETWEEN THE MUTTONVILLE NATURAL GAS STORAGE FIELD AND THE MGI PILAT #1-24 WELL

LENOX TOWNSHIP, MACOMB COUNTY, MICHIGAN

Case No. 2:20-cv-12600-SDK-APP
United States District Court, Eastern District, Michigan

April 2022

Prepared for

ANR PIPELINE COMPANY

Prepared by

Dowdle & Associates, Inc.
Petroleum Engineering Consultants

Contents

Detailed Contents

EXECUTIVE SUMMARY

At the request of ANR Pipeline Company, Dowdle & Associates has evaluated information related to contended pressure communication between the Muttonville Natural Gas Storage Field and the Pilat #1-24 well located in Macomb County, Michigan, approximately ¼ mile southeast of the Muttonville field in the NE/4 of the NE/4 of Section 24, Lenox Township. On the basis of our evaluation, it is our opinion, to a reasonable degree of engineering certainty,[1] that Muttonville and the Pilat well are not, and have never been, in pressure communication through the subsurface and, thus, that gas migration has not and cannot occur from the Muttonville field to the Pilat well. This report summarizes the basis for that conclusion.

[1] As defined herein, an opinion reached to a reasonable degree of engineering certainty is one arrived at by a qualified engineer using all the pertinent available information and employing industry accepted engineering techniques and scientific concepts.

1. BACKGROUND

Michigan Geosearch, Inc. ("MGI") operates the Pilat #1-24 well ("Pilat") located in the NE/4 of the NE/4 of Section 24, Lenox Township, Macomb County, Michigan (see Figure 1).[2] Approximately ¼ mile northwest, in the same township and county, ANR Pipeline Company ("ANR") owns and operates the Muttonville Natural Gas Storage Field ("Muttonville"). In 1994, MGI apparently first became aware that Pilat well pressures were building up during shut-in periods and concluded that the cause was storage gas migrating from Muttonville through the subsurface.

Following various subsequent communications between ANR and MGI concerning the matter, MGI filed a Complaint against TC Energy, Inc. on September 22, 2020, in the United States District Court, the Eastern District of Michigan,[3] in which it alleged that storage gas migrating from Muttonville caused damages. In August, 2021, Dowdle & Associates was asked by ANR to evaluate whether or not Muttonville could be in pressure communication with the Pilat well as a result of subsurface gas migration associated with Muttonville gas storage operations. The results of our evaluation are presented in the sections which follow.

[2] Complaint, Case No. 2:20-cv-12600-SDK-APP United States District Court, Eastern District, Michigan.
[3] *Ibid.*

2. QUALIFICATIONS

Mr. Dowdle has over 45 years consulting experience in the oil and natural gas industry. He has studied fields worldwide, including those containing black oil, dead oil, volatile oil and dry gas, retrograde gas and near-critical fluids. He has performed numerical simulation studies of oil reservoirs producing under depletion drive, water drive, gas-cap expansion, compaction drive, combination drive and gravity drainage, in addition to volumetric, over-pressured and water-drive gas reservoirs. His simulation experience includes secondary and tertiary recovery processes, such as waterflooding, gas injection pressure maintenance, and CO2 miscible EOR.

Dowdle has extensive deepwater GOM (Gulf of Mexico) simulation experience including:

- Allegheny (AGIP)
- Bass Lite (BHP Billiton)
- Vortex (BHP Billiton)
- Rigel (Dominion)
- Matterhorn (Elf)
- WC 580 (Pennzoil)
- Zia (Marubeni)

Internationally, he has evaluated fields in Canada, Mexico, South America, the North Sea, West Africa, the Middle East, Pakistan, Malaysia, Indonesia, China, Australia, New Zealand, and other countries throughout the world. A partial list includes:

- Numerous (Mexico, Pemex)
- Numerous (Venezuela, BP and LASMO)
- Loma LaLata (Argentina, YPF)
- El Vinalar Block (Argentina, Golden Oil)
- Yaguara (Colombia, PetroBras)
- Snorre (Norwegian North Sea, arbitration)
- Alba (Equatorial Guinea)
- Zafiro (Equatorial Guinea)
- Lion Oil Reservoir (Cote d'Ivoire, UMC Petroleum)
- Panthere Field (Offshore Cote d'Ivoire, United Meridian International Corp.)
- Yombo (Congo, Addax Petroleum)
- Qarun (Egypt, Apache)
- Pindori Field (Pakistan, POL)
- Numerous, (Central Luconia Sarawak, Shell)
- Oyong (Indonesia, El Paso Production Company)
- CFD 11-6/12-1 (China, Kerr McGee)
- Maui (New Zealand)

With regard to underground natural gas storage, he has performed studies of more than 100 fields throughout the U.S. and others in Australia, Canada, South America and the Middle East. These studies

include deliverability evaluations of fields located in Louisiana, Maryland, Mississippi, Oklahoma, Pennsylvania and other states. He has performed numerous pressure-inventory studies, and evaluations of recoverable base-gas. He has been involved in several screening studies to identify potential gas storage sites, including an effort which eventually led to the commercial development of a major Gulf Coast salt dome storage facility. He served as a consultant for two companies in regulatory filings related to reclassification of working gas to base gas and with other companies in similar matters dealing with the Internal Revenue Service. Currently, Dowdle is retained as a consultant in inventory verification and reserves on over 90 active storage fields for major interstate pipeline companies. His experience in numerical simulation covers nearly 45 years and includes modeling of gas storage reservoirs.

Dowdle holds BS and MS degrees in Petroleum Engineering from Mississippi State University and Stanford University, respectively. Upon graduation from Mississippi State, he was employed by Chevron Oil Company, where he worked as a reservoir engineer and well log analyst. After six years with Chevron, he joined Intercomp, a major international consulting firm specializing in numerical simulation. His work there included several consulting assignments, the last being Vice President, Domestic Consulting, which included management of the Reservoir Engineering, Geology-Petrophysics and Gas Projects Divisions, emphasizing evaluation of enhanced oil and gas recovery. He formed an independent consultancy in 1981 and has been with Dowdle & Associates since 1991. A registered Professional Engineer in the States of Texas and Mississippi, he has been qualified as an expert witness with the Federal Energy Regulatory Commission, the Louisiana Office of Conservation, the Utah Oil and Gas Board and in other litigation matters.[4]

Mr. Dowdle has not testified as an expert at trial or by deposition in any matter in the past four years. Compensation paid for this analysis is computed on an hourly basis, using the rates set forth on the fee schedule included in Appendix I.

[4] See Appendix I for other details.

3. GEOLOGICAL CONSIDERATIONS

❖ **Pressure communication via storage-gas migration between Muttonville and the Pilat well through geological strata is highly improbable due to the absence of sufficiently porous and permeable formation rock intervening between Muttonville and Pilat.**

Muttonville is a pinnacle Niagaran reef of Silurian age located in southeast Michigan occurring at a depth of about 2600 ft from the surface. It was found to contain natural gas upon discovery in 1966 and was subsequently developed as a production field. Seven wells were drilled during the years from 1966 through 1968. By 1975, these wells had recovered a total of approximately 9.1 Bcf[5] of native gas when the field was converted to underground natural gas storage. Ten additional wells were drilled as part of storage development from 1975 to 1977.

The Pilat structure, located southeast of the Muttonville storage field, is a deeper, considerably smaller, incipient reef lying at a depth of approximately 2700 ft (Figure 1). Pilat #1-24, drilled in 1977 after storage operations at Muttonville began, was the discovery well. To date, total Pilat gas production is reported as 1.2 Bcf.

The Muttonville storage field is ringed by eleven dry holes[6] (see yellow circles on Figure 2). Core analyses, wireline log interpretations and, in some cases drill stem tests, deemed these wells non-commercial as the Niagaran formation they penetrated was found to be off-reef, down-dip low-porosity, low-permeability rock. Likewise, less than 200 ft southeast of the most southeasterly boundary of Muttonville, a dry hole, the Lopatkiewicz #1, also was drilled down-dip on the Pilat structure (orange circle on Figure 2). It was not completed as a commercial well for the same reasons as those which encircle Muttonville outside its productive limits.

Consideration of these dry holes alone points to the conclusion that, geologically, Muttonville and Pilat were deposited as two distinct shallow-water reefs separated by non-reefal deposits. This is consistent with Friedman and Kopaska-Merkel [1991] who state that pinnacle reefs of the Michigan Basin form

[5] Bcf is an abbreviation for billion standard cubic feet, herein expressed at a pressure base of 14.73 psia and temperature of 60 °F.

[6] “Dry hole” is an industry term for a non-commercial well, usually designated on geological maps with a “dry hole” symbol.

isolated hydrocarbon reservoirs encased in impermeable evaporates and mudstones (see Figure 3). Elsewhere, Niagaran reefs are referred to as “closed pressure vessels.”[7]

For storage gas to reach the Pilat well from the Muttonville storage field, it would have to be displaced by a pressure differential though a sufficiently porous and permeable subsurface stratum common to both reefs. The twelve dry holes mentioned above indicate that the Brown Niagaran formation between the two structures is not adequately porous and permeable for such displacement, but rather is non-reefal, non-productive and poor-quality carbonate rock saturated with water, consistent with the nature of typical reef development in the Michigan basin [Kopaska-Merkel]. It is therefore concluded, to a reasonable degree of engineering certainty, that pressure communication via storage-gas migration between Muttonville and the Pilat well through such a stratum is highly improbable.

[7] See TC500068.

4. FLUID FLOW EFFECTS

❖ **Even if the Brown Niagaran were sufficiently porous and permeable between the structures, for which there is no evidence, storage gas displacement would confront an extended water leg impediment that proceeds downdip from Muttonville and then back updip to the reservoir level of the Pilat bottom perforation.**

The Muttonville reservoir is limited by a downdip gas-water contact (GWC)[8] at 2186 ft TVDss (true vertical depth below sea level in feet, usually shortened to "ft ss"), while the extent of the Pilat accumulation is taken to be the HKW (highest known water) seen in the non-commercial MCGC Lopatkiewicz #1 well (L-1) at 2159 ft ss. A structural saddle is mapped northwest of the L-1 well between the non-reservoir base of the Muttonville structure and the non-productive base of the Pilat bioherm, which could be as low as 2219 ft ss (Figure 1). As discussed in Section 3, available data suggests that the Brown Niagaran formation in this "saddle" area has low porosity and permeability. Even if it were sufficiently porous and permeable, however, fluid flow effects limit the ability of gas to migrate from Muttonville to the Pilat well.

In order for gas to migrate from Muttonville to the Pilat well, storage gas would have to be forced down through water-saturated rock (in effect an aquifer), displacing between 14 and 33 vertical feet of water, to spill out of the Muttonville structure and across the saddle. The distance from the lowest point of the saddle to the Pilat HKW is between 41 and 60 vertical feet. Thus, for storage gas to migrate from Muttonville to the lowest known extent of the Pilat gas accumulation, it would first have to be pushed down a vertical distance some 14 to 33 ft, then back up another 41 to 60 vertical feet before reaching the HKW in the Pilat structure. And then, to reach the bottom perforation in the Pilat well at 2119 ft ss, storage gas would ultimately need to be displaced vertically upward an additional 40 ft, or vertically upward from the spill point 81 to 100 ft for a total down-up distance of 95 to 133 ft through a water saturated formation.

It is unreasonable to expect that gas could migrate from Muttonville to the Pilat well given these circumstances. Further, any such migration would have resulted in "watering out"[9] the Pilat well or in its

[8] A "gas-water contact" is the depth of a bounding surface in a reservoir above which predominantly gas occurs and below which predominantly water occurs; it is often referred to as a "reservoir limit," meaning a limit of gas accumulation in the reservoir.

[9] When a flowing gas well also begins to produce associated water, the water-gas ratio (usually expressed in barrels of water per million standard cubic feet of gas) can increase to a point where the fluid "head" (the weight of the fluid column), becomes too heavy for the well to continue flowing. When this happens, a well is said to "water out." For production to continue after that, artificial lift is required.

production of substantial volumes of water that would have been pushed ahead of migrating gas. But, according to available records, the Pilat well did not "water out" or produce water in any significant quantities, let alone the water volumes that would have been required to have been displaced.

Displacement of a fluid through a porous and permeable medium requires a pressure differential, capillary pressure in excess of the entry threshold, sufficient cross-sectional area for flow, an adequately low viscosity and relative permeability to the subject fluid. Because it is non-wetting, the gas phase requires a certain minimum saturation (percentage of pore volume) before any flow can take place. This value is known as the "critical saturation" and once created, that quantity of gas is trapped in the pore space. This saturation is typically on the order of 3 to 5 percent, which in this instance would require an estimated volume of immobile gas equivalent to 135-225 MMcf[10] before any free-flowing storage gas could begin to be displaced toward the Pilat well. Under any plausible scenario, due to threshold capillary pressure and relative permeability effects alone, it would not be logical to conclude, even if the Brown Niagaran intervened and were sufficiently porous and permeable (and the evidence indicates it is not), that storage gas could be displaced downdip through a water leg of the extent discussed above to reach the bottom Pilat perforation.

[10] MMcf is an abbreviation for one million standard cubic feet.

5. DISCOVERY PRESSURES

❖ **It is unrealistic to expect that, if in communication with Muttonville, reservoir pressure at the Pilat well upon initial completion in 1978 would have experienced no decrease at all following more than 1060 psi of pressure decline (greater than 80 percent depletion) at Muttonville during primary production; because discovery pressure at the Pilat was at hydrostatic conditions, this indicates that the Pilat and Muttonville structures were not in pressure communication at discovery and, hence, have never been.**

As mentioned, Muttonville was discovered in 1966 and was developed as a natural gas production field. The field's discovery pressure was 1217 psig wellhead (WHP).[11] Prior to storage conversion in 1975, average reservoir pressure had declined to 218 psig WHP. Not long afterward in 1977, the Pilat #1-24 was completed and recorded an initial pressure of 1211 psig WHP, practically the same as the Muttonville discovery pressure when adjusted to the same datum.

If the Pilat and Muttonville structures were in pressure communication, the original fluid potentials and datum pressures before production in both would have been the same; *i.e*., in gravity-capillary pressure equilibrium through a common aquifer or "water leg." As illustrated in Figure 4, by 1974 at the end of seven years of primary production, culminating in a reservoir pressure decline of more than 1060 psi, Muttonville had reached a negative 1.82 million cumulative pound-days[12,13] [Katz and Coats; Katz and Lee] and WHP had declined to 218 psig. During this entire time and before the Pilat discovery well, Muttonville was a "sink" that afforded a pressure differential between itself and the Pilat structure that became larger and larger. If Muttonville and the Pilat structure were in communication, the initial equilibrium would have altered causing the Pilat gas accumulation to expand, thereby lowering its discovery pressure. This expansion in turn would have displaced water in the aquifer common to the two structures into the Muttonville reservoir thereby providing additional pressure support. Yet, the Pilat

[11] As the name suggests, wellhead pressure (WHP) is measured at the wellhead on the surface. Bottomhole pressure (BHP) is measured, or calculated from WHP, near the bottom of the well normally with a pressure instrument run on wireline to some established datum, which often is at the measured depth (MD) midpoint of the casing perforations. For a given measurement, BHP is greater than WHP due to the weight of gas (or fluid) in the hole.

[12] Reservoir pressure one psi lower than discovery pressure for one day equals one negative pound-day. The pound-day concept, the validity of which Katz *et al* [1959] tested with a series of calculations, was originally developed to explain, or "model," water movement into and out of (influx and efflux) aquifer gas storage reservoirs, but the method can also be useful in evaluating water-drive gas reservoirs. A water-drive gas reservoir is one in which water from an associated aquifer influxes into or effluxes from—and possibly beyond—the reservoir depending on its pressure.

[13] Katz and Lee [1990] explain that the reasoning behind the pound-days method is basically that positive cumulative pound-days results in contraction of the gas "bubble," whereas, negative cumulative pound-days leads to expansion of the gas "bubble." The degree to which either happens is proportional to the value of pound-days. Naturally, for a given volume of gas in-place (say, that at discovery), contraction of the gas pore volume results in a higher reservoir pressure and, conversely, expansion of the gas pore volume results in a lower reservoir pressure.

discovery pressure, as mentioned, was practically the same as Muttonville's and, as will be shown later, Muttonville's pressure-production and pressure-inventory performance shows it to be a completely volumetric reservoir; *i.e.*, it functions entirely by pressure-depletion/gas-expansion drive with no water influx or support from any other gas accumulation through a common aquifer.

Although having undergone two storage cycles when the initial pressure was measured on the Pilat, Muttonville cumulative pound-days remained practically unchanged from the end of primary production to that point (see Figure 4). It is unrealistic to expect—after seven years of primary production at Muttonville, as average pressure declined 1000 psi to 218 psig WHP, followed by only two storage cycles operated at near zero average keywell pressure above discovery (Figure 5)—that, if in communication with Muttonville, pressure at the Pilat at the time of completion in 1977 would have experienced essentially no decline at all from that when the reservoir was originally formed in geologic time (*i.e.*; from hydrostatic pressure). In fact, the opposite would be expected, namely, that the initial pressure measured on the Pilat would have been considerably lower than 1211 psig WHP. The lack of any pressure decline attributable to Muttonville primary production demonstrates that the Pilat and Muttonville structures were not in pressure communication at discovery and, hence, have never been.

6. PRIMARY PRESSURE-PRODUCTION PERFORMANCE

❖ **Pressure-production performance demonstrates that both Muttonville and Pilat are volumetric reservoirs with reservoir energy during depletion having come entirely from the expansion of their individual, volumetrically-contained native gas; however, Pilat shut-in bottomhole pressures require extended build-up periods in order to approach average reservoir pressure due to production from tight reservoir rock and possible formation damage at the well.**

The *p/Z* versus cumulative gas production plot is well-known in the oil and natural gas industry as a means of determining original gas in- place (OGIP). Its counterpart, *p/Z* versus total gas content (GIP),[14] is widely used throughout the underground gas storage industry as a primary method for verifying storage gas inventory. These plots are more or less mirror images governed by the fundamental physical law known as the Real Gas Equation of State (Real Gas Law). The basis of this law is straightforward: at constant temperature, the pressure within a constant-volume container is proportional to the amount of gas it contains. Because real gases do not behave ideally, a correction factor called the gas compressibility or gas deviation factor, given the symbol, *Z*, is necessary so that pressure divided by *Z*, or *p/Z*, is *directionally* proportional to gas content.

The Real Gas Law expressed in equation form, but rearranged slightly from that usually published is:

$$p/Z = nRT/V \tag{1}$$

where:

p	average reservoir pressure, psia
V	volume, scf
Z	gas compressibility factor, dimensionless
n	number of pound moles (lb moles)
R	universal gas constant, psia-scf/lb mole-°R (10.732)
T	average reservoir temperature, °R

From Eq. (1), it can be seen that a plot of *p/Z* versus *n* for a container of constant volume *V* will be a straight line passing through the origin with a slope of *RT/V*, provided *T* is constant, which is the case for most all subsurface hydrocarbon reservoirs.

Gas storage reservoir engineers typically utilize a material balance equation derived from Eq. (1) that is based on volumes rather than moles as given below:

[14] In the gas storage industry, the symbol for *p/Z* is usually written as *BHP/Z* to make clear that what is being plotted is BHP divided by *Z*, not WHP divided by *Z*.

$$p/Z = GIP(p/Z)_i/G \tag{2}$$

and newly introduced variables are

GIP	gas in-place at any given time or pressure, Mcf
G	gas in-place at p_i , T_i and Z_i (i = reference conditions), Mcf
$(p/Z)_i$	discovery (p/Z), psia

In the exploration and production side of the business, the following relationship, also derived from Eq. (1), is used:

$$p/Z = (p/Z)_i(1 - G_p/G) \tag{3}$$

where G_p is the symbol for cumulative gas production. Used in this way, G (G is the equation symbol for OGIP) can be determined by extrapolation of the theoretical straight line of a plot of p/Z vs G_p to $p/Z = 0$. The slope of the line is $(p/Z)_i/G$, the same as in Eq. (2). As covered later, the reciprocal of this slope is known as "gas-per-pound" in gas storage engineering.

6.1 Muttonville

Shut-in pressure data obtained during Muttonville's primary production period are summarized in Table 1. Figure 6 is a *p/Z* plot of these data (black circles) along with an interpreted trend-line (red) that represents conditions at discovery of 10.715 Bcf gas in-place at a *p/Z* of 1625 psia. As can be seen, the *p/Z* data points lie in a near perfect straight line from initial conditions to the last point at which average WHP was calculated to be 217.6 psig from measurements taken on October 6, 1974, following a six-month field shut-in test.

Muttonville's *p/Z* trend as illustrated in Figure 6 is a text-book case of straight-line volumetric reservoir performance per Eq. (3), which means that throughout primary production, reservoir energy at this field was supplied entirely by expansion of the *in-situ* native gas*; i.e.*, there was no significant water influx or pore-volume compaction. It also implies that no energy was supplied by contribution or interference from any other gas reservoir via subsurface communication such as through a down-dip water leg. If water influx had occurred or another reservoir had interfered, the line in Figure 6 would not be straight [Bruns *et al*, Agarwal, *et al*].

As mentioned earlier, the reciprocal slope of the discovery line in Figure 6 is generally referred to as "gas-per-pound" and is important in verifying inventory in storage reservoirs because it uniquely establishes the size of the reservoir gas pore volume at discovery. For example, *p/Z* vs gas in-place plots, which are based on storage field semi-annual shut-in tests, should have approximately the same gas-per-pound slope as the discovery line, provided gas pore volume remains the same. On the other hand, should gas pore volume become expanded, say due to delta-pressuring,[15] gas-per-pound will trend to higher values.

6.2 Pilat

6.2.1 Pressure-Production History

Pilat #1-24 commenced production in June 1978, since then having reportedly produced approximately 1.2 Bcf as of the end of January 2020, the last month of available records. The well's gas production has been suspended for four intervals during this time: from 1985-1990, from 1994-2001, from 2014-2017 and from the last part of 2019 to the date of this report. These intervals are depicted in Figure 7, a plot of monthly gas production vs time. This plot shows that during the first two continuous production periods, and part of the third, over which the major portion of the gas was produced, initial rates declined sharply in each. This can be explained by Figure 8 where measured bottomhole pressures are plotted along with monthly production rate.

When the well was placed on production following a shut-in interval, rates were relatively high, but then fell off sharply as pressure was drawn down. This is particularly noticeable in the first production period when gas rates peaked at over 20 MMcf per month, then, within about two years, fell to half this amount. At that point, measured bottomhole pressure also had declined sharply—nearly 500 psi (about 40 percent). Due to the preceding higher rates and insufficient shut-in time, however, the July 1980 pressure had not yet stabilized. By the end of the production period in mid 1985, rates had fallen to less than 2 MMcf per month and bottomhole pressure would have been correspondingly lower also.

The same behavior occurred during the second production period (about mid 1990 to mid 1994). Due to pressure buildup during the prior five year shut-in, initial rates rebounded to over 7.5 MMcf per month from about 2 MMcf per month at the end of the first period. But as before, monthly volumes again

[15] "Delta pressuring" is the term given to operating a storage field above its discovery pressure at maximum contents.

quickly dropped to around 2 MMcf. Note that when production ceased in mid 1994, pressure built up significantly during the following long shut-in period from the middle of 1994 to the latter part of 2001 (over seven years).

A longer third period of production lasted from late 2001 to the end of 2013. After an initial peak, again about 7.5 MMcf per month, production held at an average of about 2.9 MMcf per month. During the following shut-in that lasted a little over three years, bottomhole pressure built up about 70 psi. The rate of pressure buildup was not as great as it was following the second period; however, the period three average monthly rate was fairly low as mentioned.

Overall, the pressure-production behavior of the Pilat well seen in Figure 8 and described here is characteristic of low-quality, low-permeability ("tight") reservoir rock and could also reflect skin damage (or formation damage)[16] on the Pilat well. This is further demonstrated by the Pilat *p/Z* trend as discussed in Section 6.2.3 below, but following next is a brief discussion of a field with similar performance, Capac.

6.2.2 Comparison with Capac

The Capac field, discovered in 1961 and located in St. Clair and Lapeer Counties, Michigan, was operated as a production field until 1978, thereafter serving as a storage facility until November 2004. At that time, the field was abandoned from storage service and production of its base gas began and has continued to the present time. As of August 2021, cumulative base gas recovery had exceeded estimated recoverable reserves by more than 35 percent [STS, 2020].

Capac, like Pilat, is a structural-stratigraphic trap that developed from a localized, low-relief bioherm mound within the Middle-Silurian Brown Niagaran formation. Capac abandonment-production follows a pattern of sharp rate declines rebounding after pressure builds up during shut-in periods, as illustrated in Figure 9 (production is shown by the red triangle symbols and line, while the open circles and black line denotes pressure). This is not due to influence from another storage field; instead, it is behavior typical of production from a low-quality, low-permeability reservoir.

In gas pools of this type (and oil fields also), withdrawals create a localized pressure "sink" around the well or in the field heartland. After a period of time, the pressure in this sink becomes too low for the well

[16] Formation damage (skin) is a zone of reduced permeability within the vicinity of the wellbore as a result of foreign-fluid invasion into the reservoir rock, but also can be impedance to the flow of fluids into (or out of) a wellbore due to numerous other causes, such as mud cake, salt precipitation, fines accumulation, etc. (PetroWiki https://petrowiki.spe.org/Formation_damage).

or group of wells to flow due to physical or economic limitations.[17] At that point the well or field is shut-in and gas from the field peripheries eventually recharges the sink sufficiently for production to begin again at higher rates [STS, 2020].[18] As can be seen by comparing Figures 8 and 9, and as described above in Section 6.2.1, production performance of the Pilat well has followed a similar pattern, which is consistent with the performance of low-permeability reservoirs.

6.2.3 *p/Z* Performance

Figure 10 is a *p/Z* plot of the Pilat pressure-production data given in Table 2. Also plotted on Figure 10 is the well's monthly gas production rate plotted against cumulative gas production. Original gas in-place (OGIP) in the Pilat accumulation is estimated to be approximately 2.52 Bcf as shown by the red straight line. The early bottomhole pressures, when cumulative production was less than 0.6 Bcf and production rates were highest, were measured after shut-in times insufficient to allow build up to average reservoir pressures represented by the discovery line. This is also true for most pressures around a cumulative of 0.7 Bcf, except the February 2001 BHP, which was nearly stabilized. By the time the Pilat well had produced about 1.16 Bcf and rates had declined to 2.5 MMcf per month or less, the BHP measured in November 2016 after a shut-in period of just about three years was approximately stabilized at average reservoir pressure and lies on the discovery line as shown.

It is not difficult to understand why, in view of Figure 10, that several early estimates of OGIP in this structure turned out to be low, some extremely low.[19] As a result of low reservoir permeability, possibly combined with formation damage at the well itself, BHPs measured on the Pilat simply were not fully built up and, thus, not representative of average reservoir pressures until cumulative production had reached about 1.16 Bcf and production rates had fallen to low levels. While it may not have seemed so early in the well's life, Figure 10, which includes the most recent data, demonstrates that the Pilat is an individual, volumetrically-isolated, low-permeability reservoir with an original gas-in place of approximately 2.52 Bcf.

[17] Due to low formation permeability or flow capacity, wells in these kinds of reservoirs characteristically produce with steep, near-wellbore pressure gradients similar to an inverted cone. At the well, pressure is considerably lower than further out away from the wellbore. As average reservoir pressure declines with production so does that in the "cone" and eventually pressure becomes too low at the well for it to physically or economically flow. This condition is exacerbated if the wells have skin damage.
[18] In oilfield jargon, this is sometimes referred to as a "huff-and-puff" process. This is somewhat of a misnomer as it usually applies to cyclic injection-soak-production such as in steam or enhanced oil recovery.
[19] See TC002428 and TC002424.

In regard to possible communication with Muttonville, consider again Figure 5. This graph shows that annual Muttonville keywell pressure has averaged about 140 psi above wellhead discovery pressure (1217 psig) since 1980. This corresponds to a calculated bottomhole pressure of 1470 psia. On November 7, 2016, bottomhole pressure measured on the Pilat well was 771 psia. If, after being in communication with such high pressure as what existed concurrently at Muttonville for nearly 40 years —nearly double that recorded in 2016—to conclude that the Pilat well would be receiving any kind of pressure support from Muttonville, much less migrated gas, is implausible. Rather, to reiterate, based on geological interpretations confirmed by analysis of its pressure-production performance and other information, Pilat is a volumetric, low-transmissibility reservoir not pressure-connected to Muttonville.

7. MUTTONVILLE RESERVOIR INTEGRITY

❖ **Inventory verification at Muttonville, which has been an ongoing process since storage operations first began at the field, has consistently confirmed the volumetric integrity of the Muttonville reservoir with no storage gas migration having occurred through the subsurface.**

7.1 Overview

ANR Pipeline Company regularly and systematically analyzes all its storage fields, including studies that are undertaken to confirm storage gas inventory. This has been done at Muttonville since the field was first converted to storage service. Such assessments have consistently verified that the reservoir integrity of the Muttonville storage field is sound, and that no loss of storage gas has occurred or is occurring due to storage gas migration through the subsurface.

Based on annual inventory verification studies, two book adjustments have been made at Muttonville since the field was converted to storage in 1975. The first was a deduction of 0.50 Bcf made in 2003 after studies by Storage Technical Services (STS) and outside experts at Southwest Research Institute (SwRI) concluded that pulsation issues (compression effects) had caused metering errors that resulted in overstated gas injection volumes. The other, a deduction of 0.75 Bcf in 2016, was found—again after considerable investigation by STS—to be due to measurement error.

Further, in August 2020, a book deduction of 489 MMcf was made based on confirmation by the Measurement group that its investigation had found a discrepancy occurred during the 2016-2019 timeframe. Studies by STS, which is responsible for inventory verification of all TC Energy storage fields, initiated that investigation. In addition, Accounting frequently makes "Prior Period Adjustments," but these are booked during the storage cycle, along with other customary deductions. Other measurement issues at this field have been related to improper operation of manual valves and improper cleaning and maintenance of meter-run tubes. The recent *2020 Muttonville Unresolved Gas Investigation Study* [STS, 2020] and numerous prior studies have shown that pulsation and measurement issues may still be occurring at Muttonville.

A discussion of Muttonville's historical pressure-inventory performance is presented below. The basic data related to this discussion are given in Table 5 of STS's 2020-2021 Inventory Report [STS, 2021].

7.2 Pressure-Inventory Performance

Results of Muttonville's semi-annual shut-in pressure-inventory tests are shown in Figure 11, a plot of *BHP/Z* vs Total Field Content. The discovery line (solid red) passes through the point 1625 psia at 10.715 Bcf as covered in Section 6.1. The dashed red line is an extension of the discovery line to the FERC[20] certificated top content, 13.414 Bcf. Open circles represent the well weighted-average *BHP/Z* points at the Fall and Spring (high-content and low-content) shut-ins.

As can be seen, the cycling of this field along the discovery line is remarkably consistent, demonstrating the continued volumetric nature of the Muttonville reservoir under storage operations as was evidenced during primary production (Figure 6). The Fall (high content) points occur mostly at total contents above 12 Bcf and nearly all plot very close to the discovery line; so do most Spring points when total content is above about 8.5 Bcf. At contents lower than this, Spring *BHP/Z* values lie below the volumetric line. The reason for this is that Spring shut-in tests are typically conducted following a time period when withdrawal rates have been considerably higher than those in the preceding Fall when storage gas was re-injected at lower rates over a longer time. Consequently, shut-in pressures at the Fall tests normally are more stabilized (closer to average reservoir pressure) than those in the Spring when shut-ins tests usually are not conducted for a long enough time period for well pressures to build up to a level closer to the reservoir average.

An example of this is shown by the 1978-79 and 1979-80 cycle lines (green and blue, respectively) on Figure 12 along with the other historical pressure-inventory points. Note that the Fall points for both cycles plot right on the discovery line, but both Spring points lie below it. In both these cycles, book inventory and gas in-place in the storage reservoir were clearly in agreement as the Fall points confirm, although each cycle did exhibit a volume of non-effective gas.[21]

At no time during its history has Muttonville displayed any sign of reservoir expansion. It was pointed out at the end of Section 6.1 that gas pore volume expansion is characterized by gas-per-pound slopes that trend to higher values than that of the discovery line. Figure 11 shows no such trend. In fact, it can be

---

[20] FERC is an acronym for the Federal Energy Regulatory Commission.

[21] Non-effective gas (NEG) is a volume of gas that does not exhibit a pressure response in the reservoir when a pressure decline analysis (PDA) is performed based on the Fall and Spring shut-in pressure data, which data, in general, are not necessarily indicative of fully stabilized reservoir conditions. Non-effective gas is not necessarily equivalent to "lost gas" or gas that has migrated beyond the confines of the storage reservoir.

inferred from Figure 12 that the gas-per-pound slopes of the cycle lines plotted there are lower than that of the discovery line. This is the case with most all Muttonville cycle lines.

But physically, in order for storage gas to migrate from Muttonville to the Pilat structure, the original reservoir gas pore volume would first have to expand down-dip from the GWC at 2186 ft ss to the mapped spill point between the two structures at 2200+ ft ss. Assuming similar reservoir quality, the volume between the GWC and the spill point is estimated to be roughly 25 percent the size of Muttonville's original pore volume. Such a large expansion would manifest itself clearly in an increasing and pronounced gas-per-pound trend. The dashed black line on Figure 13 represents this expansion, toward which historical pressure-inventory points should have trended in this eventuality, but plainly they did not (Figures 11, 12 and 13). Considering nothing else, this alone renders subsurface migration of storage gas from Muttonville an implausible postulate.

Nevertheless, for the sake of argument, assume for the moment that the Muttonville reservoir were in communication through a water leg below its GWC with the Pilat structure. In such an event, this would mean that both Pilat and Muttonville would in effect be water-drive reservoirs. If so, according to Katz [Katz and Coats], following primary depletion, in order to grow the Muttonville gas pore volume back to its *original* size, cumulative pound-days would need to become positive. Figure 4 shows that this did not actually occur at Muttonville until after 2011. Growth to a size great enough for gas to begin to migrate to the Pilat structure under this assumption could not take place until well after 2022.

8. CONCLUSION

To a reasonable degree of engineering certainty, the Muttonville field and the Pilat well are not, and have never been, in pressure communication as a result of subsurface gas migration associated with gas storage operations at Muttonville. There are several independent reasons for this conclusion:

a) As shown in Sections 3 and 4, there is no supportable geological means that would afford communication between these two structures and, even if there were, the intervening water leg would be an impediment to gas flow.

b) As shown in Section 5, the discovery pressure on the Pilat well itself demonstrates no communication with Muttonville because it exhibited unchanged hydrostatic conditions after years of depletion at Muttonville that amounted to a 1000 psi pressure decline and millions of negative pound-days.

c) As shown in Section 6.1, primary production performance of Muttonville shows that it behaves as a volumetric vessel with reservoir energy having come entirely from the expansion of its volumetrically-contained native gas.

d) As shown in Section 6.2, historical production performance indicates that Pilat shut-in bottomhole pressure requires an extended build-up period in order to approach average reservoir pressure, which is a consequence of production from tight reservoir rock and possible formation damage at the well rather than due to communication with Muttonville.

e) As shown in Section 7, assessments of storage gas inventory at Muttonville, which have been conducted annually since storage operations first began at the field, have consistently verified that the volumetric integrity of the Muttonville reservoir is sound and that no measureable loss of storage gas has occurred or is occurring due to storage gas migration through the subsurface.

DOWDLE & ASSOCIATES, INC.
Texas Registered Engineering Firm F-18579

By: ______________________

STATE OF TEXAS
WALTER L. DOWDLE
35687
LICENSED
PROFESSIONAL ENGINEER

Walter L. Dowdle, P.E. #35687 TX
President

9. REFERENCES[22]

Agarwal, R.G., Hussainy, R. and Ramey, H.J. Jr.: "The Importance of Water Influx in Gas Reservoirs," *JPT*, p 1336, November, 1965.

Brock Engineering, LLC: Brock, T.J. to Fodor, T.F.: Pilat 1-24, September 23, 2020.

Bruns, J.R., Fetkovich, M.J. and Meitzen, V.C.: "The Effect of Water on *p/Z*-Cumulative Gas Production Curves," *JPT*, p 287, March, 1965.

Friedman, Gerald M. and Kopaska-Merkel, David C.: "Late Silurian Pinnacle Reefs of the Michigan Basin," Special Paper 256, Geological Society of America, 89 ff (1991).

Katz, Donald L. and Coats, Keith H.: *Underground Storage of Fluids*, Ulrich's Books, Inc. Ann Arbor, Michigan,186, 223, 491-492, Fourth Printing (1978).

Katz, Donald L. and Lee, Robert L.: *Natural Gas Engineering Production and Storage*, McGraw-Hill Publishing Company, p 545, 1990.

Katz, D. L., Tek, M.R. and Coats, K.H.: "Effect of Unsteady State Aquifer Motion on the Size of an Adjacent Gas Storage Reservoir," *Trans.* AIME, Vol. 216, pp 8, 247 (1959).

Lemmon, E.W. and Huber, M.L.: "REFPROP: Reference Fluid Thermodynamic and Transport Properties," NIST Standard Reference Database 23, Version 9.1, 2015.

McCain, William D. Jr.: *The Properties of Petroleum Fluids*, PennWell Publishing Company, second edition, 1990.

Storage Technical Services (STS), TC Energy: "Comparison of Production of Capac Production Field after Abandonment from Storage Service with Pilat 1-24 Production Field," Inter-Corporate Correspondence, Luke Dewig to Susan Burla, October 16, 2020 (TC 500437).

Storage Technical Services (STS), TC Energy: "Muttonville Unresolved Gas Investigation," Inter-Corporate Correspondence, 2020 (TC116580).

Storage Technical Services (STS), TC Energy: "Storage Field Inventory Report, Muttonville Final Draft, 2020-2021," September, 2021 (TC119125).

---

[22] Additional documents that were provided and that were considered in conducting this analysis are listed in Appendix II.

TABLES

Table 1
Muttonville Primary Production Data*

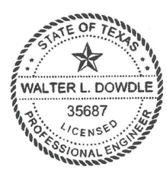
Date	Shut-in (days)	Avg WHP (psig)	Cumulative Production, Mcf 15.025 psia	Cumulative Production, Mcf 14.73 psia	*p/Z* (psia)	BHP (psia)
10/20/1967	Initial	1217.0	0	0	1625.2	1316.8
12/20/1967	5	1146.5	683,169	696,851	1516.1	1241.4
12/10/1968	8	913.0	2,971,667	3,031,181	1168.1	993.0
12/29/1969	8	758.6	4,444,281	4,533,287	947.3	827.2
11/18/1970	44	440.6	7,062,968	7,204,419	526.1	486.1
10/6/1974	6 mos	217.6	8,896,647	9,074,822	258.2	248.2

*Basic data from TC500001

Table 2

Pilat #1-24 Primary Production Data

Date	BHP (psig)	Cum Prod (Mcf)	*Z*	*p/Z* (psia)
5/5/1977	1317.0	0	0.798	1668.2
7/9/1980	825.4	247,287	0.865	971.4
6/9/1994	399.2	717,577	0.865	971.4
7/31/1994	413.0	717,577	0.930	460.0
9/2/1994	435.0	717,577	0.926	485.5
9/30/1994	458.2	717,577	0.923	512.5
4/20/1995	556.3	717,577	0.907	629.7
6/2/1995	561.4	717,577	0.906	635.9
8/14/1995	562.8	717,577	0.906	637.6
11/29/1995	575.3	717,577	0.904	652.8
4/26/1996	610.8	717,577	0.898	696.5
8/14/1996	613.9	717,577	0.898	700.3
12/17/1996	617.2	717,577	0.897	704.3
12/30/1999	804.4	717,577	0.868	943.7
2/20/2001	896.6	717,577	0.854	1066.8
7/21/2008	748.2	997,575	0.877	870.3
12/3/2013	684.7	1,163,643	0.887	788.9
9/30/2014	696.8	1,163,645	0.885	804.3
7/23/2015	726.1	1,163,645	0.880	841.8
1/21/2016	742.7	1,163,645	0.877	863.2
11/7/2016	756.2	1,163,645	0.875	880.7
4/6/2020	744.4	1,203,395	0.877	865.4
5/11/2020	745.5	1,203,395	0.877	866.8



FIGURES

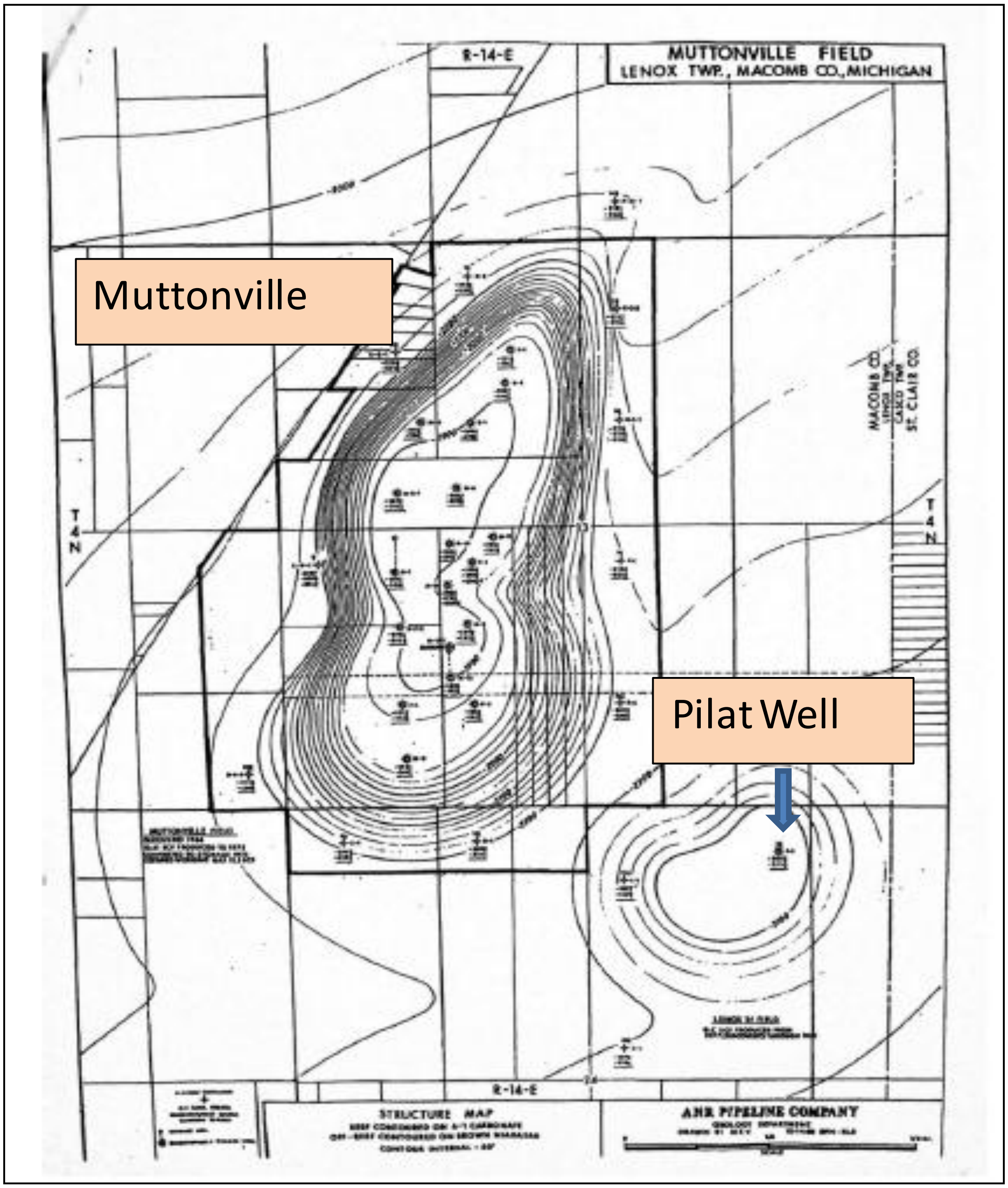


Figure 1. Muttonville Field structure map also with Pilat structure, ANR Pipeline Company, (pp 1-1, 3-1, 4-1) [Complaint, Case No. 2:20-cv-12600-SDK-APP]

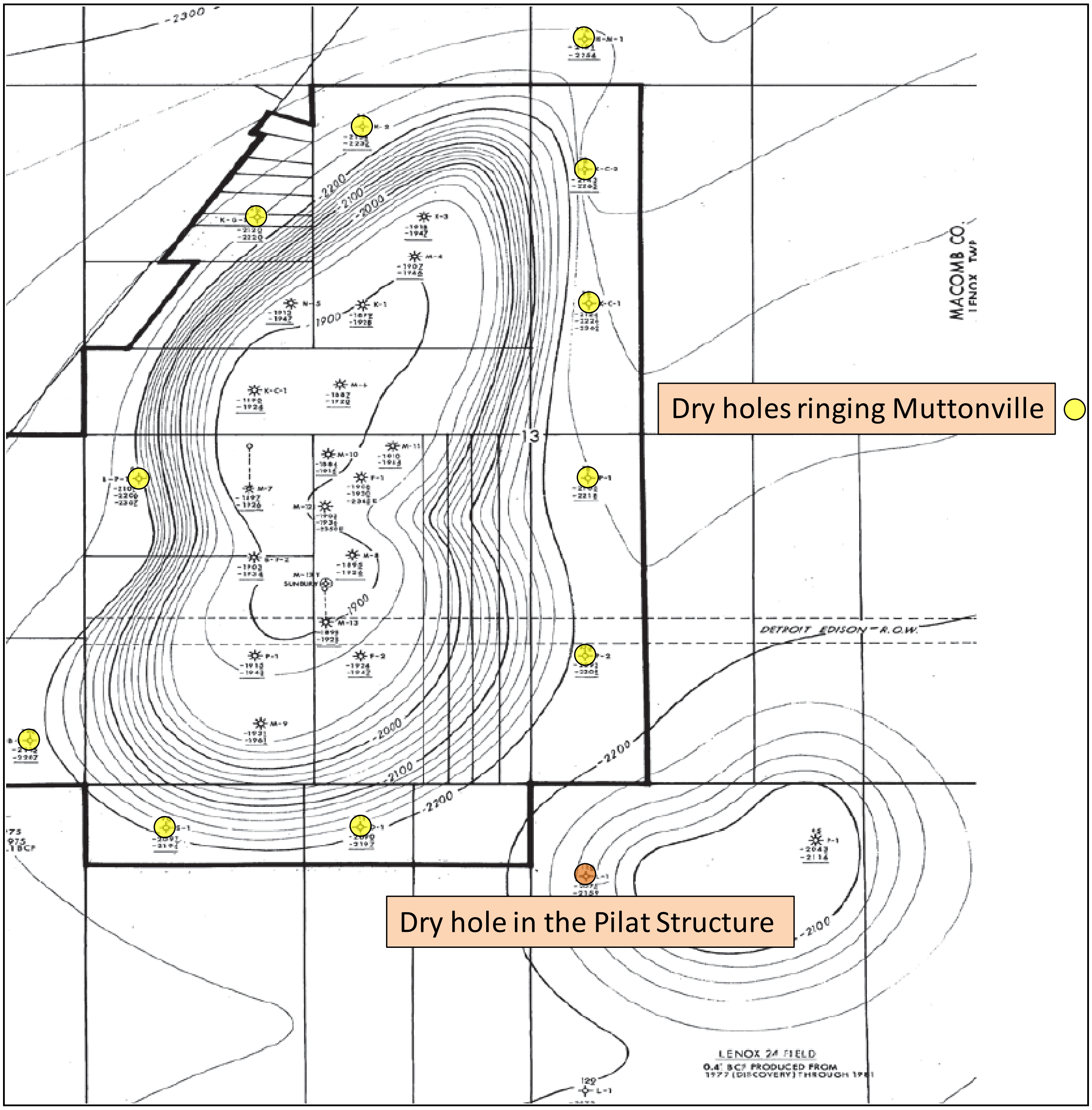
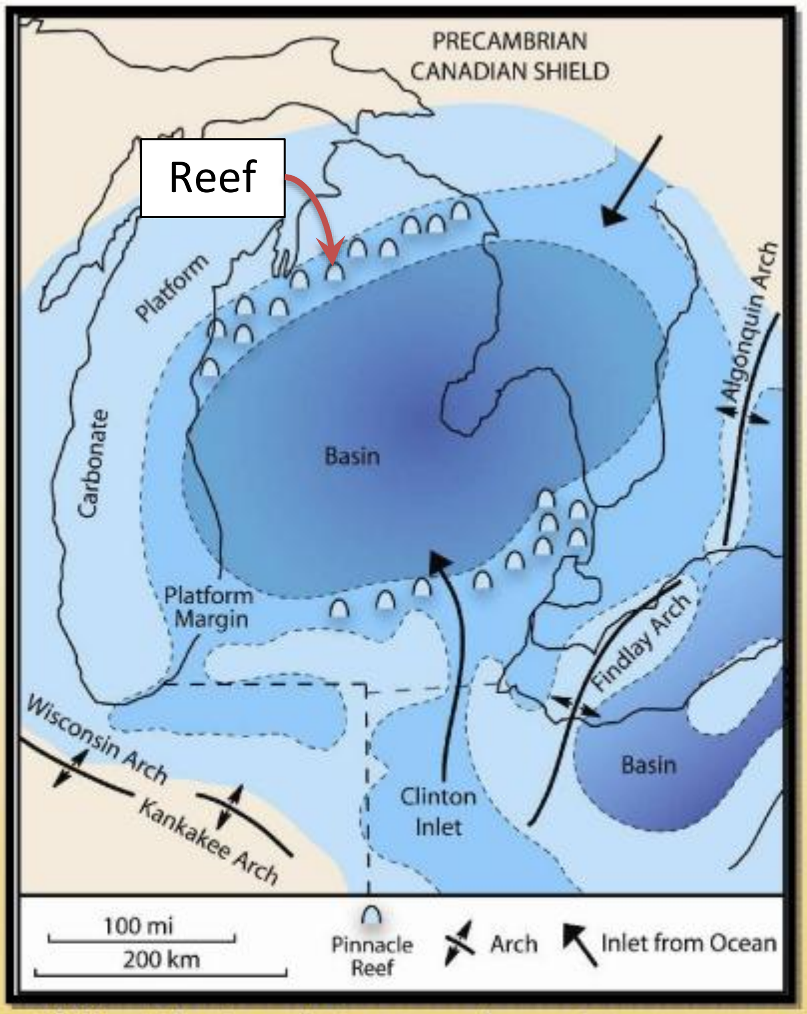


Figure 2. Muttonville showing dry holes ringing the structure and the dry hole in the Pilat structure, Mid Michigan Gas Storage Company, (p 3-1) [Storage Technical Services or STS, 2021]



Middle Silurian (Niagaran) environments in the Michigan Basin (modified from Briggs et al., 1980)

Figure 3. Depiction of Michigan Niagaran reefs and environs, (p 3-1) [Friedman and Kopaska-Merkel]

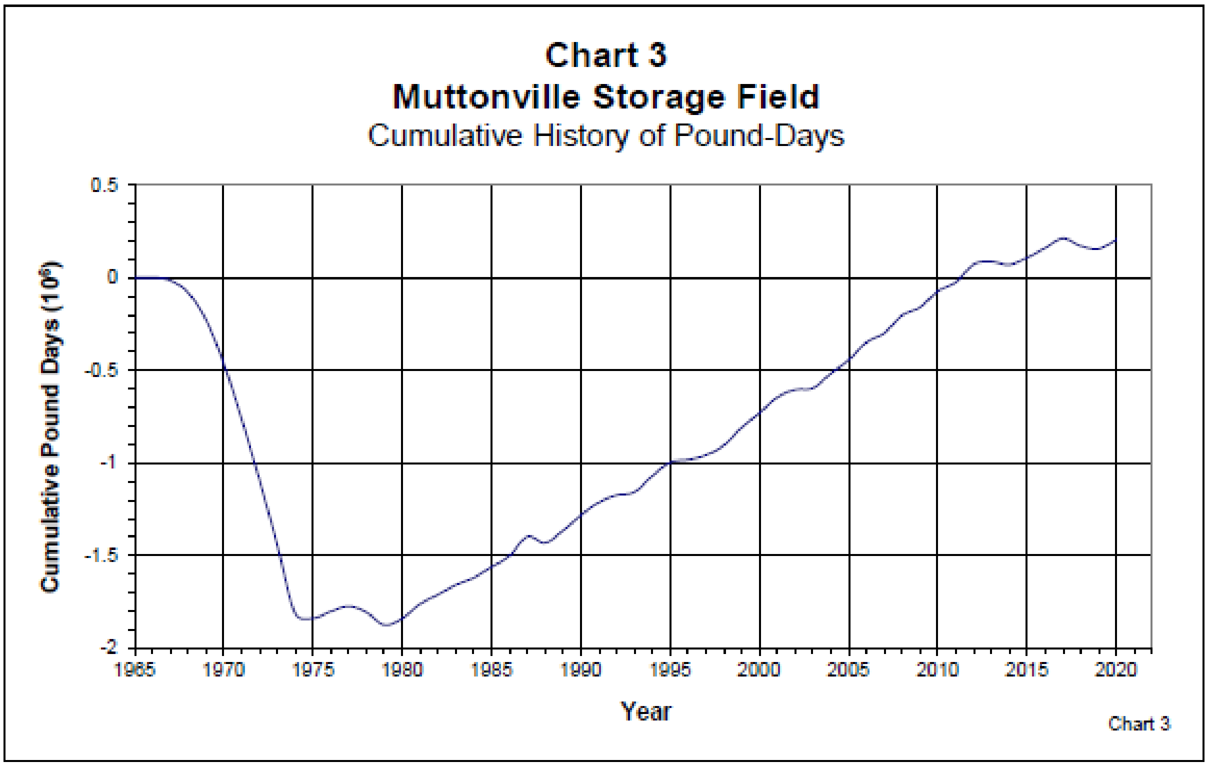


Figure 4. Cumulative pounds-days vs time, Muttonville Field, (pp 5-1,2, 7-3) [STS, 2021]

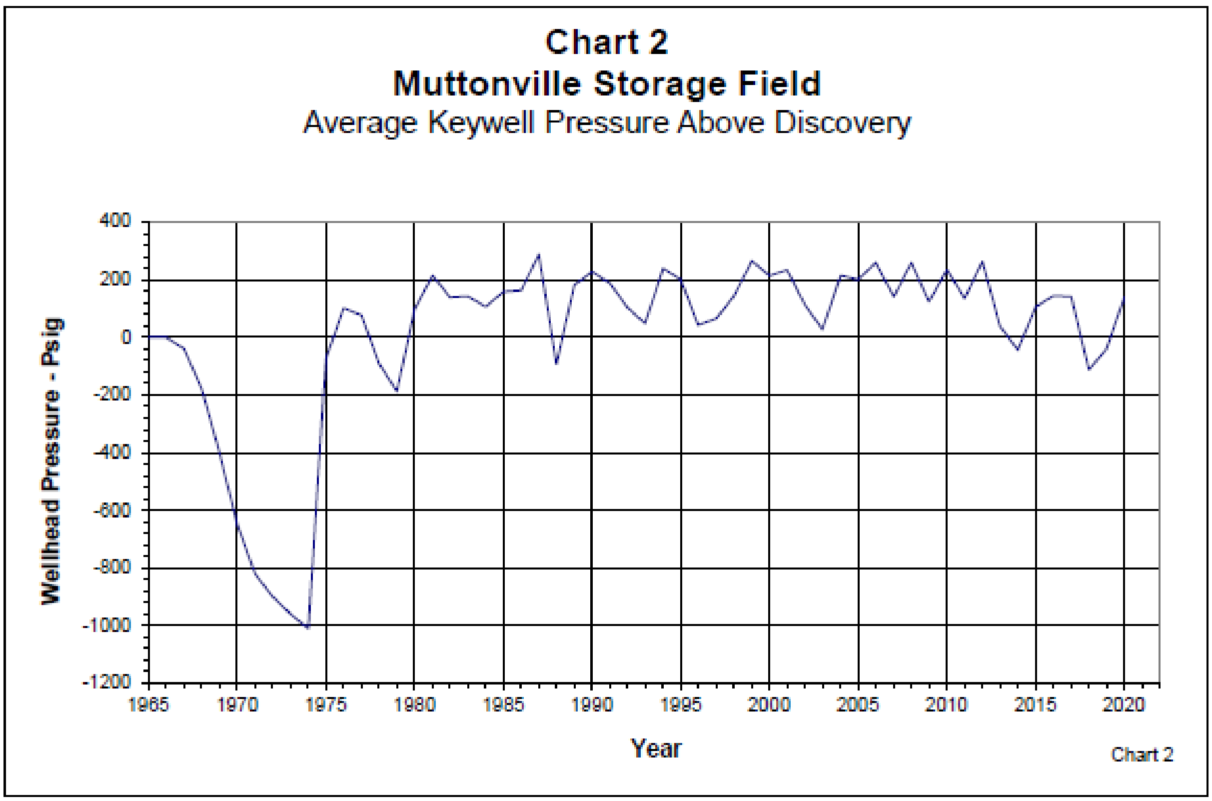


Figure 5. Average annual keywell wellhead pressure above discovery pressure vs time, Muttonville Field, (pp 5-2, 6-6, 7-2) [STS, 2021]

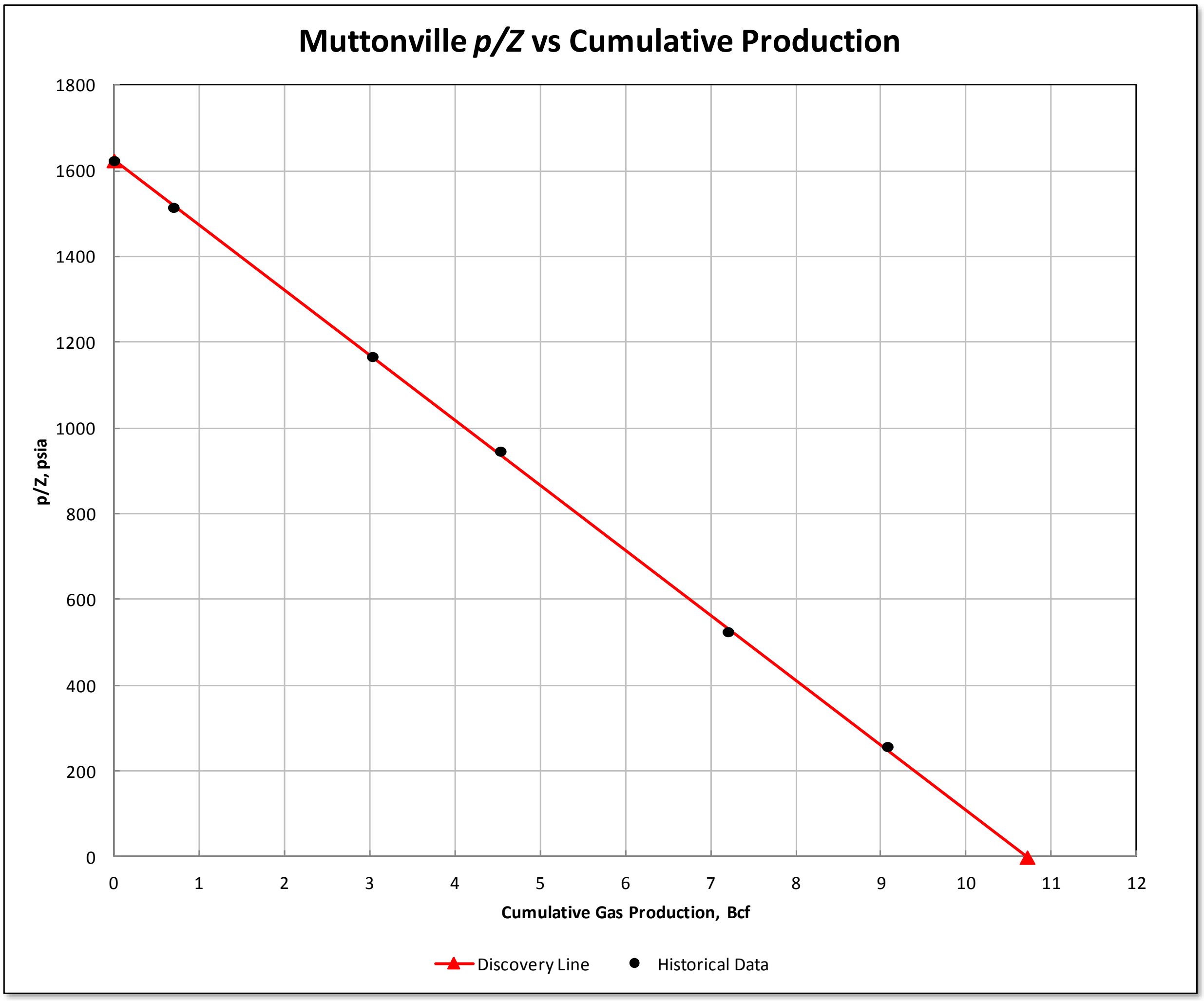


Figure 6. Muttonville *p/Z* vs cumulative gas production during primary depletion and discovery-line extrapolation to original gas in-place, (pp 6-2,3)

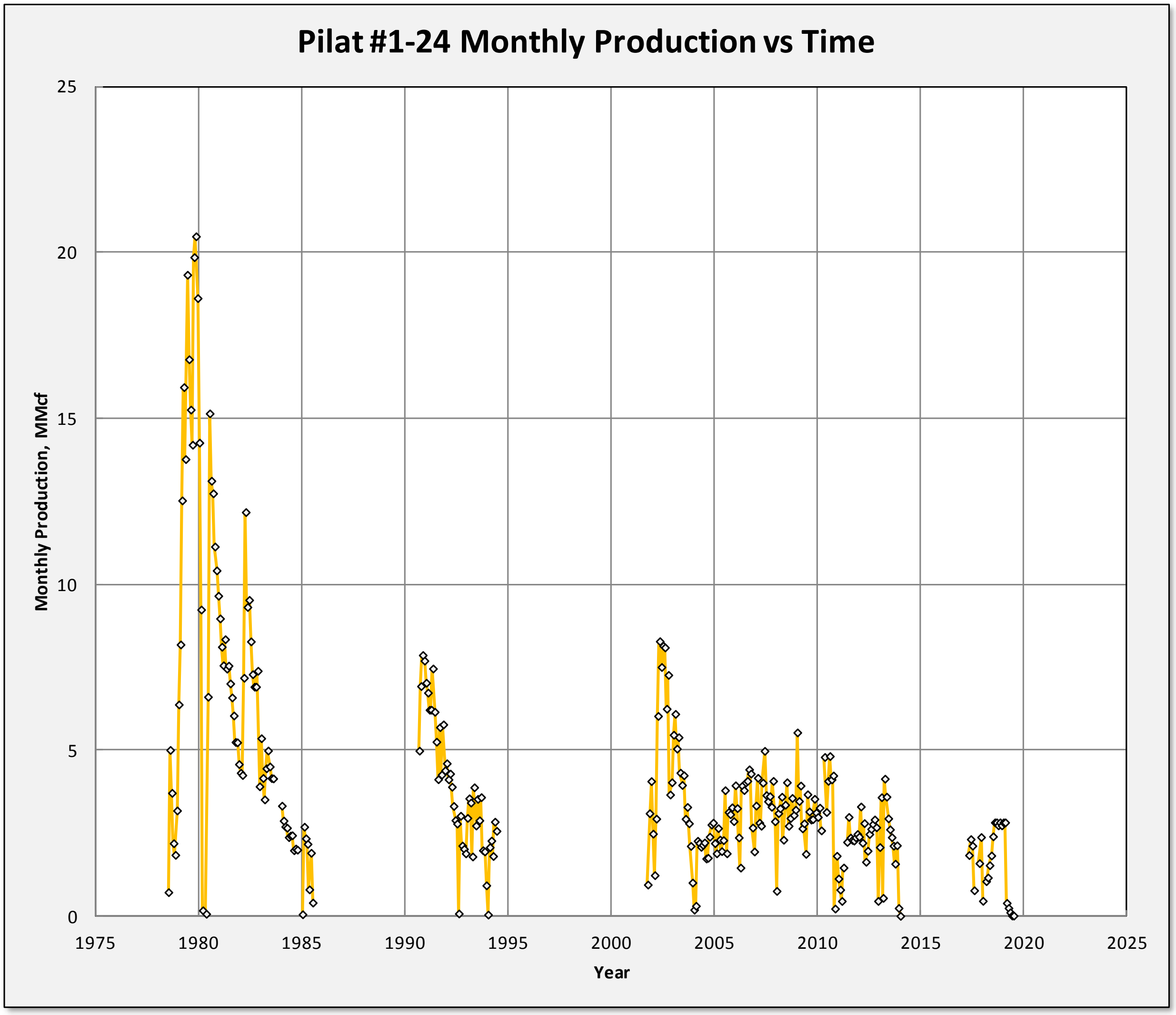


Figure 7. Pilat monthly production vs time, (pp 6-3, 7-2)

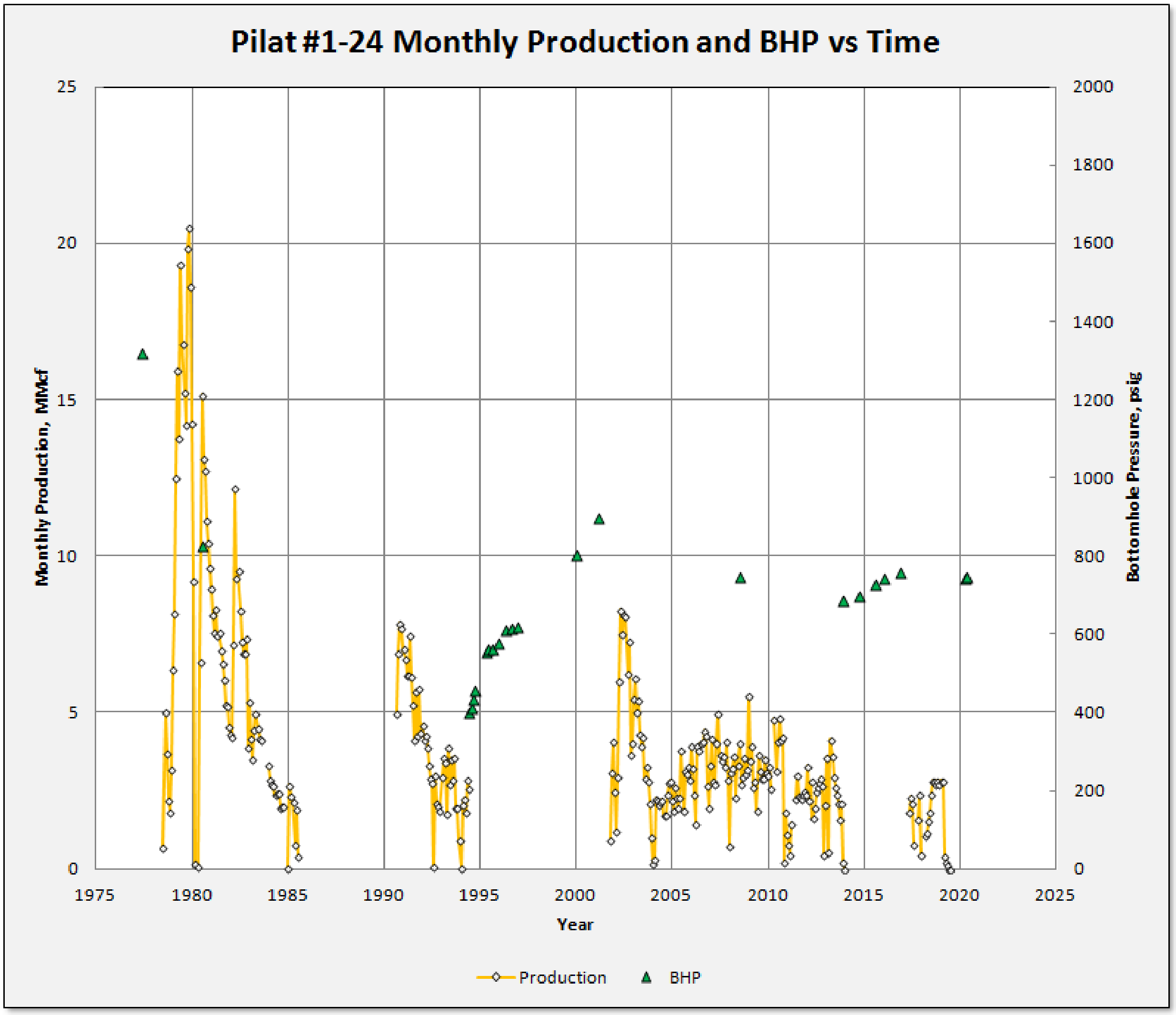


Figure 8. Pilat monthly production and measured bottomhole pressures vs time, (pp 6-3,4,5)

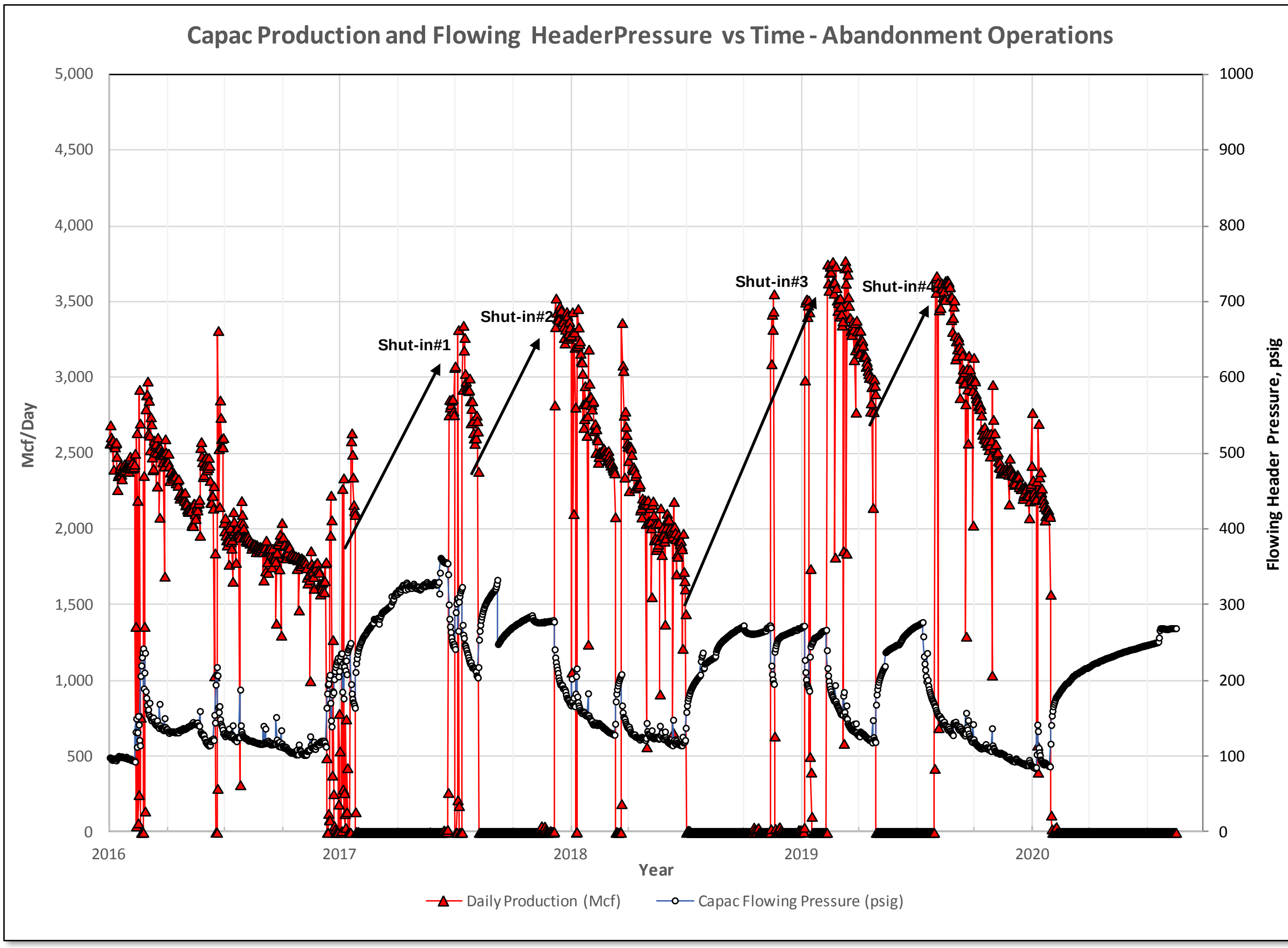


Figure 9. Capac daily production and flowing header pressure vs time, (pp 6-4,5) [STS, 2020]

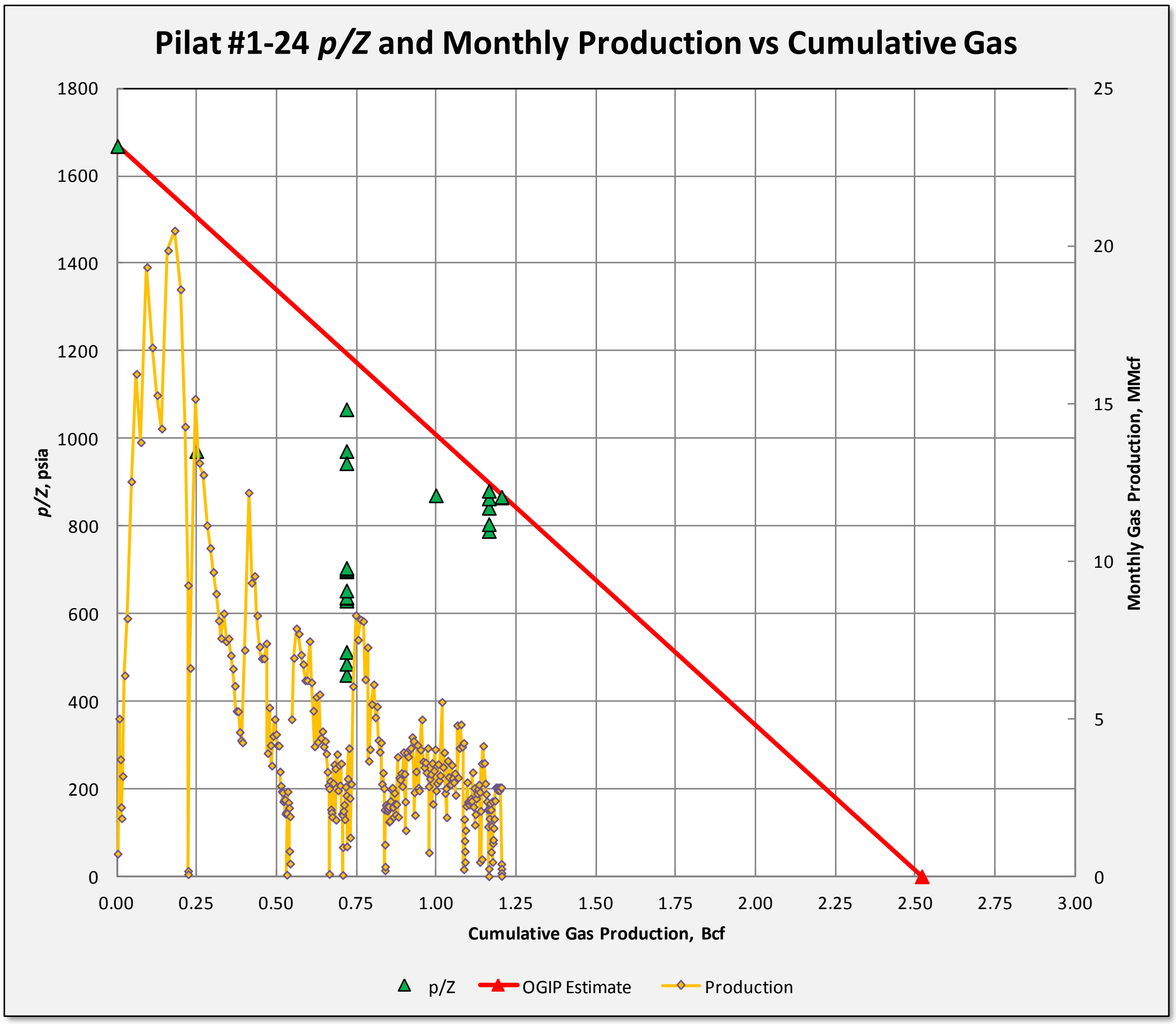


Figure 10. Pilat *p/Z* and monthly gas volumes vs cumulative gas production with discovery-line extrapolation to original gas in-place, (pp 6-5)

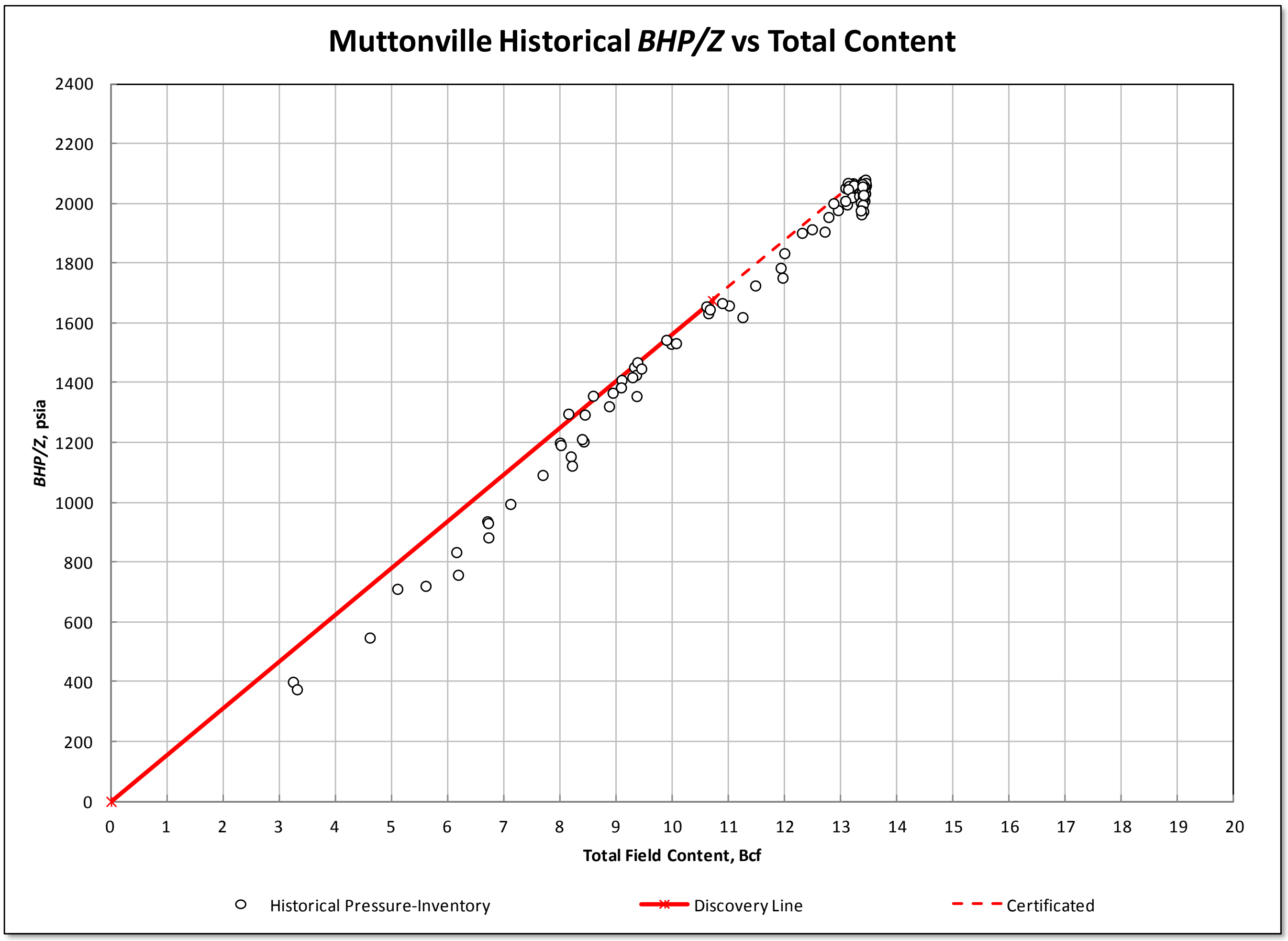


Figure 11. Muttonville historical semi-annual shut-in *BHP/Z* vs total content with discovery line, (pp 7-2,3) [STS, 2021]

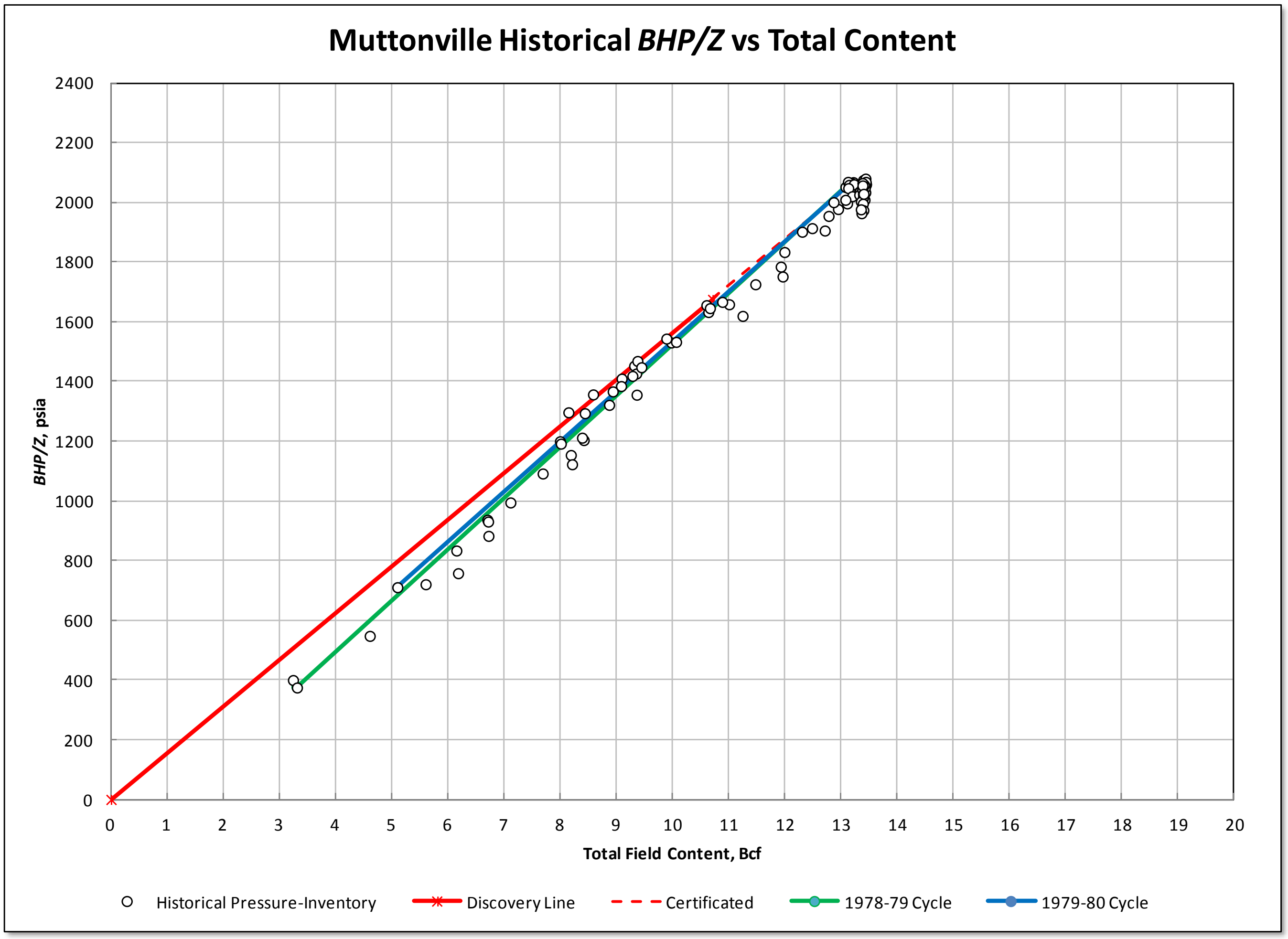


Figure 12. Muttonville historical semi-annual shut-in *BHP/Z* vs total content with discovery line and 1978-79 and 1979-80 cycle lines, (pp 7-2,3) [STS, 2021]

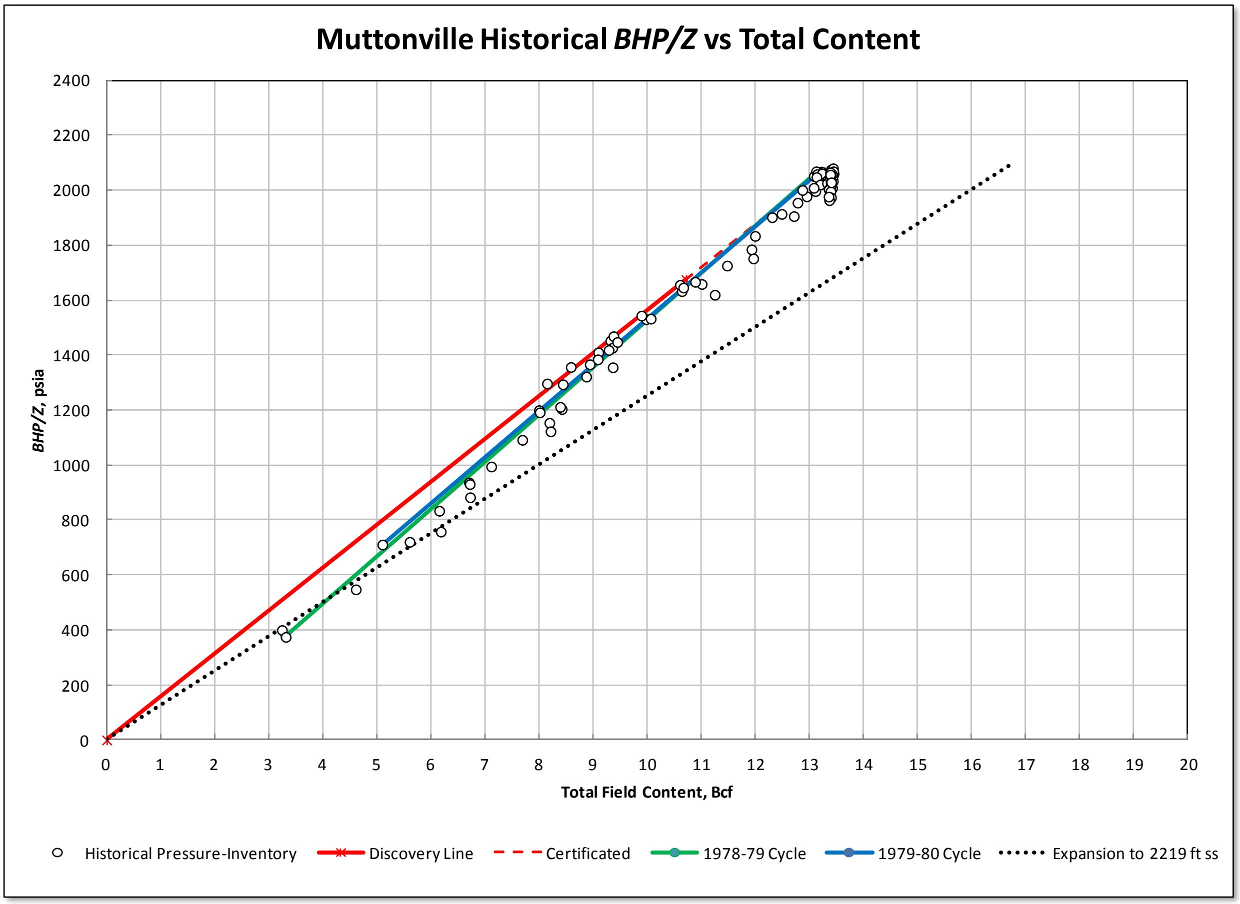


Figure 13. Muttonville historical semi-annual shut-in *BHP/Z* vs total content with discovery line and 1978-79 and 1979-80 cycle lines, along with dashed line representing a 25% expansion of gas pore volume, (pp 7-3) [STS, 2021]

APPENDIX I

WALTER L. DOWDLE

EDUCATION

M.S. Petroleum Engineering, Stanford University, 1970.
B.S. Petroleum Engineering, Mississippi State University, 1967.

EXPERIENCE

Years	Brief Description
1991–Present	President, Dowdle & Associates, Inc. Consultant in reservoir description and engineering, natural gas engineering and underground storage, enhanced oil recovery, reservoir simulation, property appraisals and well log analysis.
1981–1991	President, Dowdle Fairchild & Ancell, Inc. Specializing in reservoir engineering studies, natural gas storage inventory verification and deliverability, reservoir simulation, pressure transient test analysis, well log analysis and property appraisals.
1980–1981	Vice President, Galactica Enhanced Oil Recovery Corporation. Responsible for property acquisitions, evaluations, reservoir engineering, and corporate planning.
1979–1980	Vice President, Domestic Consulting, INTERCOMP Resource Development and Engineering, Inc. Responsible for all domestic operations projects performed in the Houston office. Chief duties included management of Reservoir Engineering, Geology-Petrophysics and Gas Projects Divisions, emphasizing evaluation of enhanced oil and gas recovery.
1977–1979	General Manager, Reservoir Engineering Division, INTERCOMP Resource Development and Engineering, Inc. Responsible for coordination, supervision, and execution of numerical simulation studies in the area of reservoir engineering.
1974–1977	Engineering Consultant, INTERCOMP Resource Development and Engineering, Inc. Responsible for client studies in reservoir engineering. Performed oil-in-place studies using digital well log processing, gas storage evaluations, miscible coning analyses, and property appraisals.

EXPERIENCE (cont'd)

Years	Brief Description
1972–1974	Well Log Analyst, Chevron Geophysical. Computer processed well logs from operating companies and worldwide affiliates of Standard Oil Company of California. Performed field studies, establishing relationships between well logs and reservoir rock parameters, to determine overall *in situ* average field properties for use in reservoir simulation projects.
1967–1972	Reservoir Engineer, Chevron Oil Company. Evaluated oil and gas fields for secondary recovery including waterflooding, pressure maintenance, and miscible gas injection. Analyzed pressure buildup and drawdown methods. Estimated reserves and economics of many Chevron properties. Limited workover and drilling experience.

INDUSTRY COURSES AND SEMINARS, 1990–2018

"Underground Natural Gas Storage School", MGRRE Facility, WMU, Kalamazoo, Michigan, September 12-14, 2017.
"Estimating Reserves in Unconventional Resources", SPE Webinar, SPE Training Courses, February 23, 2012.
"Risk and Uncertainty Basics for Unconventional Reservoirs", SPEE Short Course, 2011 Annual Conference, Amelia Island FL, June 5, 2011.
"Shale Gas Production Data Analysis – The Physics of Decline Curve Analysis for Shales – A Defendable Hyperbolic", SPEE Short Course, 2011 Annual Conference, Amelia Island FL, June 7, 2011.
"Modern Production Decline Analysis", SPE Short Course, 2008 ATCE, Denver CO, September 20-21, 2008.
"Miscible Displacement Workshop (CO_2 Flood)", ExxonMobil Upstream Research Company, April 10-12, 2001.
"Optimizing Reservoir Performance by Understanding and Applying PVT Data", FESCO/HYCAL, Seminar, September 1999.
"Stochastic Reservoir Modeling Seminar", GEOMATH, Inc., September 1996.
"Pressure Transient Testing: Design & Analysis", Smith, Cobb & Associates, Inc, May 1994.
"Waterflooding", Smith, Cobb & Associates, Inc, April 1992.
"Basic Concepts of Decline Curve Analysis", SPE, M. J. Fetkovich, March 1992.
"Enhancing Recovery from Water Drive Gas Reservoirs", GRI, October – November 1990 (Instructor).

OTHER QUALIFICATIONS

Expert Witness
Federal Energy Regulatory Commission Qualified Witness
Louisiana Office of Conservation Qualified Witness
Arbitrator

HONORS, PROFESSIONAL REGISTRATIONS, AND ASSOCIATIONS

Distinguished Engineering Fellow, MSU Bagley College of Engineering
Society of Petroleum Engineers Legion of Honor
American Association of Petroleum Geologists Emeritus Member
Registered Professional Engineer: State of Texas No. 35687
Licensed Professional Engineer: State of Mississippi No. 18743LTD
Society of Petroleum Engineers International
American Association of Petroleum Geologists
Society of Petroleum Evaluation Engineers
Society of Professional Well Log Analysts

PUBLICATIONS

1. Dowdle, W.L., and Hyde, P.V., "Well Test Analysis of Hydraulically Fractured Gas Wells", SPE 6437, 1977, presented at the Deep Drilling Production Symposium in Amarillo, Texas, April 17–19, 1977.

2. Dowdle, W.L., and Cobb, W.M., "Estimation of Static Formation Temperature from Well Logs", **Journal of Petroleum Technology**, November 1975, pp. 1326–1330.

3. Dowdle, W.L., and Marsden, S.M., Jr., "Some Aspects of the Streaming Potential of Concentrated Emulsions", **Journal of Colloid and Interface Science** (Letter to the Editors), Vol. 48, No. 3, September 1974.

4. Dowdle, W.L.: "Discussion of Pressure Falloff Analysis in Reservoirs with Fluid Banks", **Journal of Petroleum Technology**, July 1974, 818; Trans., AIME, 257.

5. Dowdle, W.L., and Cobb, W.M., "A Simple Method for Determining Well Pressure in Closed Rectangular Reservoirs", JPT Forum, **Journal of Petroleum Technology**, November 1973, pp. 1305–1306.

R. LYNN McCOY

EDUCATION

M.S. Petroleum Engineering, University of Houston, 1981.
B.S. Petroleum Geology, Mississippi State University, 1975
J.D. South Texas College of Law, 1989

EXPERIENCE

Years	Brief Description
1978–present	Consulting Petroleum Engineer and Geologist. Testified as “Expert Witness” (reservoir engineer, petroleum geologist and petrophysicist) in regulatory forums and civil trials, both state and Federal. Wrote and published several software packages related to economics and evaluations, well log interpretation, waterflooding, Monte Carlo risk assessment and general reservoir engineering.
1992–present	Senior Geologist/ Engineering Associate, Dowdle & Associates, Inc.
2009–2021	E & B Natural Resources. Chief Reservoir Engineer, Sr. Technical and Legal Adviser. Provided Technical and Legal advice to Sr. Mgmt and Board of Directors.
2008–2009	EOG Oil and Gas. Reserves Engineer. Responsible for ARIES reserves database tracking assets, primarily coal-bed methane.
1988–2008	Swift Energy Company, Director of Engineering. Responsible for reservoir engineering, operations engineering and petrophysics. Developed custom petrophysical model utilizing the PRIZM package.
1975–1979	Dresser Atlas. Open Hole wire-line engineer. Responsible for the operation of HL-6104 Wireline logging unit and its crew. Ran logging services as requested by O&G operators and provide analyses of same.

OTHER QUALIFICATIONS

Expert Witness
Texas Railroad Commission, Qualified Witness
Mississippi Oil & Gas Board, Qualified Witness
Louisiana Office of Conservation Qualified Witness
Arbitrator

HONORS, PROFESSIONAL REGISTRATIONS, AND ASSOCIATIONS

State Bar of Texas (Bar # 13472980)
Society of Petroleum Engineers (40 yr. Membership award)
Society of Petroleum Evaluation Engineers (SPEE)
Society of Professional Well Log Analysts (SPWLA)
American Association of Petroleum Geologists (AAPG – Cert. Pet. Geologist)
American Institute of Professional Geologists (AIPG Certified #4784)
State of Texas – Licensed Professional Geologist No. 3338
American MENSA

PUBLICATIONS

Books

Petroleum Engineering Programs for Microcomputers, Vol. I - Reservoir Engineering and Formation Evaluation: McCoy, R. L., Gulf Publishing Co., Houston, TX. 1983

Petro-Calc 3 - Economics and Evaluation: McCoy, R. L., Gulf Publishing Co., Houston, TX. 1984

Petro-Calc 7 - Open Hole Well Log Evaluation: McCoy, R. L., Gulf Publishing Co., Houston, TX. 1985

Petro-Calc 9 – Waterflooding: McCoy, R. L. et al, Gulf Publishing Co., Houston, TX. 1985

Technical Articles

"Determining the Acoustic Velocity of Subsurface Formations from Well Log Data", McCoy et al, Society of Petroleum Engineers Paper #7435 presented at the 53rd Annual Fall Technical Conference, Houston, TX. October 1-3, 1978 and subsequently published in the Journal of Petroleum Technology, Nov. 1979, pp1453-1461.

"The Use of Interlog Relationships for Geological and Geophysical Evaluations", McCoy et al. Society of Professional Well Log Analysts, Paper G. Presented at the 20th Annual Logging Symposium, Tulsa, OK. June 3-6, 1979, ppG1-G11.

"The Analysis of Test Results from the Fairfax-Foster-Sutter No. 2", McCoy et al. Presented at the Fourth United States Gulf Coast Geopressured Geothermal Energy Conference: Research and Development, The University of Texas at Austin, October 29-31, 1979.

"Investigation and Evaluation of Geopressured-Geothermal Well- Final Report: Fairfax-Foster-Sutter No. 2 Well", McCoy et al. October 1979, Prepared for the U.S. Dept. of Energy, Division of Geothermal Energy. Available from the National Technical Information Service, U.S. Dept. of Commerce, Springfield, VA. 22161

"Synthetic Seismograms from Well Log Data", McCoy, R.L., Submitted to Dr. L.A. Jacobson as partial fulfillment of the requirements for M.S. Degree (Petroleum Engineering) at the Univ. of Houston, November 1979.

Preliminary Results of Wells-of-Opportunity Geopressured, Geothermal Testing Program", McCoy et al, SPE paper #8958,SPE/DOE Symposium on Unconventional Gas Recovery, Pittsburg, PA. May 18- 21, 1980.

Technical Articles (cont')

"Atlantic Coastal Plains Geothermal Drilling Program, DOE/Crisfield Airport No. 1 Well, Somerset County, Maryland", Volume I - Drilling and Completion, and Volume II - Well Test Analysis, McCoy et al, January 1980. Prepared for the U.S. Dept. of energy, Division of Geothermal Energy. Contract No. DE-ACO8- 78ET28373. Available from the National Technical Information Service - U.S. Dept. of Commerce, Springfield, VA. 22161.

"Fracture Identification in Devonian Shales Using Conventional Well Logs", McCoy et al. Eleventh Annual Appalachian Petroleum Geology Symposium, Morgantown, West Virginia, March 31-April 2, 1980.

"Investigation and Evaluation of Geopressured Geothermal Wells - Final Report: Beulah Simon No. 2 Well", McCoy et al, July 1980. Prepared for the U.S. Dept. of Energy, Division of Geothermal Energy. Available from the National Technical Information Service, U.S. Dept. of Commerce, Springfield, VA. 22161.

"Fracture Identification Using Conventional Well Logs", McCoy et al, World Oil, December 1980.

"San Andres Reservoir Pressure Coring Project for Enhanced Oil Recovery Evaluation, Bennett Ranch Unit, Wasson Field, West Texas", McCoy et al, SPE No. 9798. Presented at the SPE/DOE Second Joint Symposium on Enhanced Oil Recovery, Tulsa, OK, April 5-8, 1981.

"Pressure Coring Provides Innovative Approach", McCoy et al. Petroleum Engineer International, August 1981. pp 28-52.

"Well Log Analysis Applied to the Cerro Prieto Geothermal Field", McCoy et al. Presented at the Seventh Annual Geothermal Reservoir Engineering Workshop, Stanford University, California, Dec. 15- 17, 1981. Drs. H.J. Ramey and Paul Kruger, Editors.

"Microcomputer Program determines Reservoir BHP", McCoy, R.L., World Oil, August 1983.

"Handy Program Determines Condensate Dewpoint Pressure", McCoy, R.L., World Oil, pp115-117, October, 1983.

"Microcomputer Program Calculates Gas Properties", McCoy, R.L., World Oil, Nov. 1983.

JOHN R. DOWDLE

EDUCATION

Ph.D. Chemical Engineering, The University of Texas at Austin, 2011
M.S. Chemical Engineering, Stanford University, 2005
B.S. Chemical Engineering, The University of Texas at Austin, 2002

EXPERIENCE

Years	Brief Description
2011–Present	Senior Research Scientist, The Dow Chemical Company (Dow, Inc.). Global Application Technology leader for the Refining & Processing business in Dow Industrial Solutions. Responsible for technology strategy, R&D portfolio development, and global support of gas treating business development. Platform leader for carbon capture R&D projects related to the energy transition. Intellectual property focal point for the gas treating business. Lead developer for the in-house rate-based mass transfer simulation platform used for Dow's gas processing modeling & design.
1999–Present	Chemical Engineering Associate, Dowdle & Associates, Inc. Consultant in computational modeling and software development for oil & gas fluid phase behavior and thermophysical property prediction related to applications in natural gas production and storage operations.
1999–Present	Chemical Engineering Associate, Dowdle & Associates, Inc. Consultant in computational modeling and software development for oil & gas fluid phase behavior and thermophysical property prediction related to applications in natural gas production and storage operations.
2005–2011	Graduate Researcher & Teaching Assistant, Institute for Computational Engineering & Sciences, The University of Texas at Austin. Performed computational modeling of the temperature and pressure dependence of hydrophobic effects from molecular to mesoscopic length scales using simple, core-softened model liquids as well as detailed atomistic water models.
2003–2004	Chemical Engineer, Southwest Research Institute, San Antonio, TX. Assisted in the development of microencapsulation processes and materials for use in the food and pharmaceutical industries.

EXPERIENCE (cont'd)

Years	Brief Description
2000–2002	Undergraduate Researcher, McKetta Department of Chemical Engineering, The University of Texas at Austin. Characterized thin film growth processes for depositing copper diffusion barriers on dielectric materials in microelectronic devices.

PUBLICATIONS

1. J. M. Mendenhall and J.R. Dowdle. Thermodynamic correction factors to mixture fugacities in mixed solvent systems containing supercritical components. *Manuscript in Preparation. To be Submitted to Fluid Phase Equilibria*, 2022.
2. J.R. Dowdle. Rate-based modeling of selective acid gas absorption with hybrid solvents – The importance of thermodynamically consistent kinetic models. *Manuscript in Preparation. To be submitted to Industrial & Engineering Chemistry Research*, 2022.
3. J.R. Dowdle, J. M. Binz, N. Shurgott, J. Robb, and M. Robb. UCARSOL™ HYBRID Solvents: Formulated hybrid solvents tailored for organic sulfur removal applications. *Laurance Reid Gas Conditioning Proceedings*, 2019.
4. L. Wang, J. Yang, J. D. Mendenhall, D. E. Cristancho, and Dowdle, John R. An interfacial statistical associating fluid theory (iSAFT) approach for surface/interfacial tension predictions. *Fluid Phase Equilibria*, 476:193-201, 2018.
5. D. O. O. Vega, A. Badhwar, D. E. Cristancho, and J.R. Dowdle. Accurate ratebased modeling of acid gas and mercaptan removal using hybrid solvents. *Hydrocarbon Processing*, 2015.
6. J.R. Dowdle, S. V. Buldyrev, H. E. Stanley, P. G. Debenedetti, and P. J. Rossky. Temperature and length scale dependence of solvophobic solvation in a single-site waterlike liquid. *The Journal of Chemical Physics*, 138(6), 2013.
7. T. Head-Gordon, R. M. Lynden-Bell, J.R. Dowdle, and P. J. Rossky. Predicting cavity formation free energy: How far is the Gaussian approximation valid? *Physical Chemistry Chemical Physics*, 14:6996-7004, 2012.
8. J.R. Dowdle. Statistical Thermodynamics of Solvophobic Solvation in Water and Simpler Liquids. Ph.D. Dissertation, The University of Texas at Austin, 2011.

PROFESSIONAL MEMBERSHIPS & ACTIVITIES

1. Senior Member, American Institute of Chemical Engineers
2. Member, American Chemical Society
3. Member, Society of Petroleum Engineers
4. Reviewer, *AIChE Journal*
5. Reviewer, *Fluid Phase Equilibria*
6. Reviewer, *Journal of Chemical Physics*

DOWDLE & ASSOCIATES, INC.
Petroleum Engineering Consultants

FEE SCHEDULE

January 1, 2022

Dowdle & Associates, Inc. provides professional engineering consulting services to the petroleum and natural gas industry. These services include oil and gas reservoir engineering, natural gas storage engineering, numerical reservoir simulation, reserve evaluations, economic appraisals, well test analysis, geological studies, well log interpretation and technical training. Our fees are as follows:

PROFESSIONAL SERVICES

	Rate/hr
Principals	
Walter L. Dowdle, P.E.	$250.00
John R. Dowdle, PhD D&A Fellow, Chemical Engineering	$250.00
Associates	
R. Lynn McCoy, SCG/SCE Senior Geologist/Engineer	$225.00
Consulting Engineer	$200.00
Consulting Geologist	$200.00
Petrophysicist/Well Log Analyst	$200.00
Engineer	$175.00
Technician	$125.00

COMPUTING AND PROGRAM USAGE

Computer and program usage rates are applied on an as-used basis. Quotations will be furnished upon request.

EXPENSES

Automobile mileage is charged at $0.60 per mile. Photocopying is charged at $0.15 per copy. Facsimile charges are $1.00 per transaction incoming or outgoing. Telephone, deliveries, outside reproduction, travel and other out-of-pocket expenses are reimbursable at cost.

GENERAL TERMS AND CONDITIONS

All statements are payable in U.S. dollars in Houston, Texas, upon receipt.

21344 Provincial Blvd • Provincial Professional Park • Katy TX 77450-7580
Tel 281-398-8900 • Fax 281-398-8844

APPENDIX II

Transcripts of Depositions of Thomas Fodor with Exhibits

Transcripts of Depositions of Richard Gentges with Exhibits

Transcripts of Depositions of Steven Nowaczewski with Exhibits

Plaintiff's Response to Defendant's Second Set of Interrogatories and Requests for Production

Documents produced by Plaintiff, MGI000001 to MGI002545

Documents produced by Isotech, Inc. in response to subpoena, ISO000002 to ISO000769

Documents produced by J.O. Well Service and Testing in response to subpoena, JOW000001 to JOW000079

Well logs produced by Defendant, TCL000003 to TCL0000394

Documents produced by Defendant, TC000001 to TC000017, TC002370 to TC003912, TC004631 to TC004718, TC005271 to TC005309, TC005576 to TC009791, TC010850 to TC010882, TC011367 to TC011374, TC011938 to TC011945, TC014555 to TC014578, TC014580 to TC014597, TC014606 to TC015034, TC108492 to TC108521, TC120221 to TC120222, and TC500001 to TC501585

J.F. Barker & S.J. Pollock, *The Geochemistry and Origin of Natural Gases in Southern Ontario*, 32 Bull. of Canadian Petrol. Geology 313 (1984) (TC500535 to TC500548)

Andrew H. Caruthers et al., *Utility of Organic Carbon Isotope Data from the Salina Group Halite (Michigan Basin): A New Tool for Stratigraphic Correlation and Paleoclimate Proxy Resource*, 130 Geological Soc'y of Am. Bull. 1782 (2018) (TC500549 to TC500557)

Paul A. Catacosinos et al., *Structure, Stratigraphy, and Petroleum Geology of the Michigan Basin, in* Interior Cratonic Basins 561 (1990) (TC500558 to TC500600)

Karen Rose Cercone & Kyger C. Lohmann, *Late Burial Diagenesis of Niagaran (Middle Silurian) Pinnacle Reefs in Michigan Basin*, 71 Am. Ass'n of Petrol. Geologists Bull. 156 (1987) (TC500601 to TC500611)

I.D. Clark et al., *Paleozoic-Aged Microbial Methane in an Ordovician Shale and Carbonate Aquiclude of the Michigan Basin, Southwestern Ontario*, 83-84 Organic Geochemistry 118 (2015) (TC500612 to TC500621)

Keith W. Dunham, Petroleum Evolution in the Michigan Basin: An Organic Geochemical Examination (1993) (Ph.D. dissertation, University of Michigan) (TC500831 to TC00854)

Ray G. Durke et al., *Effects and Control of Pulsation in Gas Measurement*, Southwest Research Institute (TC501483 to TC501493)

Gerald M. Friedman & David C. Kopaska-Merkel, *Late Silurian Pinnacle Reefs of the Michigan Basin*, Special Paper 256, Geological Soc'y of Am. 89 (1991) (TC500855 to TC500866)

W.C. Gardner & E.E. Bray, *Oils and Source Rocks of Niagaran Reefs (Silurian) in the Michigan Basin*, Mobil Rsch. & Dev. Corp. 33 (TC500867 to TC500878)

William B. Harrison, III, *Assessment of Enhanced Oil Recovery Using Carbon Dioxide in Michigan Basin Silurian Pinnacle Reefs*, U.S. Department of Energy, Sept. 2020 (TC500879 to TC500946)

Jack H. Hybza, Thermal Maturation Modeling of the Michigan Basin (Apr. 2019) (Master's thesis, Western Michigan University) (TC500947 to TC501065)

H.A. Illich & P.L. Grizzle, *Thermal Subsidence and Generation of Hydrocarbons in Michigan Basin: Discussion*, 69 Am. Ass'n of Petrol. Geologists Bull. 1401 (TC501066 to TC501068)

Anna M. Martini et al., *Microbial Generation of Economic Accumulations of Methane Within a Shallow Organic-Rich Shale*, 383 Letters to Nature 155 (1996) (TC501099 to TC501102)

Anna M. Martini et al., *Identification of Microbial and Thermogenic Gas Components from Upper Devonian Black Shale Cores, Illinois and Michigan Basins*, 92 AAPG Bull. 327 (2008) (TC501103 to TC501115)

Anna M. Martini et al., *Microbial Production and Modification of Gases in Sedimentary Basins: A Geochemical Case Study from a Devonian Shale Gas Play, Michigan Basin*, 87 AAPG Bull. 1355 (2003) (TC501524 to TC501544)

Anna M. Martini et al., *Methane in Groundwater: Pathways, in* Encyclopedia of Water: Science, Technology, and Society (Patricia A. Maurice ed., 2019) (TC501545 to TC501555)

J.C. McIntosh et al., *Pleistocene Recharge to Midcontent Basins: Effects on Salinity Structure and Microbial Gas Generation*, 66 Geochimica et Cosmochimica Acta 1681 (2002) (TC501116 to TC501135)

J.C. McIntosh et al., *Chemical and Isotopic Evidence for Pleistocene Recharge to Silurian-Devonian Aquifers, Illinois Basin*, Ninth Annual V.M. Goldschmidt Conference (TC501136)

Jennifer C. McIntosh & Anna M. Martin, *Hydrogeochemical Indicators for Microbial Methane in Fractured Organic-Rich Shales: Case Studies of the Antrim, New Albany, and Ohio Shales*, *in* Gas Shale in the Rocky Mountains and Beyond (David G. Hill et al. eds. 2008) (TC501572 to TC501585)

Patrick I. McLaughlin et al., *The Rise of Pinnacle Reef: A Step Change in Marine Evolution Triggered by Perturbation of the Global Carbon Cycle*, 515 Earth & Planetary Sci. Letters 13 (2019) (TC501137 to TC501149)

Jeffrey A. Nunn et al., *Thermal Subsidence and Generation of Hydrocarbons in Michigan Basin*, 68 Am. Ass'n of Petrol. Geologists Bull. 296 (1984) (TC501163 to TC501182)

Mark Obermajer et al., *Compositional Variability of Crude Oils and Source Kerogen in the Silurian Carbonate–Evaporite Sequences of the Eastern Michigan Basin, Ontario, Canada*, 48 Bull. of Canadian Petrol. Geology 307 (2000) (TC501183 to TC501198)

Matthew J. Rine et al., *Linked Silurian Carbon Cycle Perturbations, Bursts of Pinnacle Reef Growth, Extreme Sea-Level Oscillations, and Evaporite Deposition*, Palaeogeography, Palaeoclimatology, Palaeoecology, 2020, at 109806 (TC501200 to TC501219)

Jürgen Rullkötter et al., *Oil Generation in the Michigan Basin: A Biological Marker and Carbon Isotope Approach*, 10 Organic Geochemistry 359 (1986) (TC501220 to TC501236)

Robert H. Shaver, *A History of Study of Silurian Reefs in the Michigan Basin Environs,* Special Paper 256, Geological Soc'y of Am. 101 (1991) (TC501238 to TC501277)

Christopher S. Swezey, *Geologic Assessment of Undiscovered Oil and Gas Resources of the U.S. Portion of the Michigan Basin*, U.S. Geological Survey Digital Data Series DDS-69-T (2015), (TC500622 to TC500830)

Erwin A. Vogler et al., *Comparison of Michigan Basin Crude Oils*, 45 Geochimica et Cosmochimica Acta 2287 (1981) (TC501278 to TC501284)

Kirk A. Wagenvelt, Thermal History of the Michigan Basin (June 2015) (Master's thesis, Western Michigan University) (TC501285 to TC501471)

T.R. Weaver et al., *Recent Cross-Formational Fluid Flow and Mixing in the Shallow Michigan Basin*, 107 Geological Soc'y of Am. Bull. 697 (TC501472 to TC501482)